

File 9D-22

Report SAM-TR-81-22

Ada 110590

SODIUM CHLORIDE RESPIRATOR QUANTITATIVE FIT TEST INSTRUMENT

Edward S. Kolesar, Jr., Captain, USAF
Colette M. de la Barre, Staff Sergeant, USAF

November 1981

Final Report for Period 16 June 1980 - 15 December 1980

20061010015

Approved for public release; distribution unlimited.

USAF SCHOOL OF AEROSPACE MEDICINE
Aerospace Medical Division (AFSC)
Brooks Air Force Base, Texas 78235



NOTICES

This final report was submitted by personnel of the Crew Environments Branch, Crew Technology Division, USAF School of Aerospace Medicine, Aerospace Medical Division, AFSC, Brooks Air Force Base, Texas, under job order 2729-00-20.

When U.S. Government drawings, specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

The voluntary informed consent of the subjects used in this research was obtained in accordance with AFR 169-3.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

Edward S. Kolesar, Jr.

EDWARD S. KOLESAR, JR., Captain, USAF
Project Scientist



RICHARD L. MILLER, Ph.D.
Supervisor

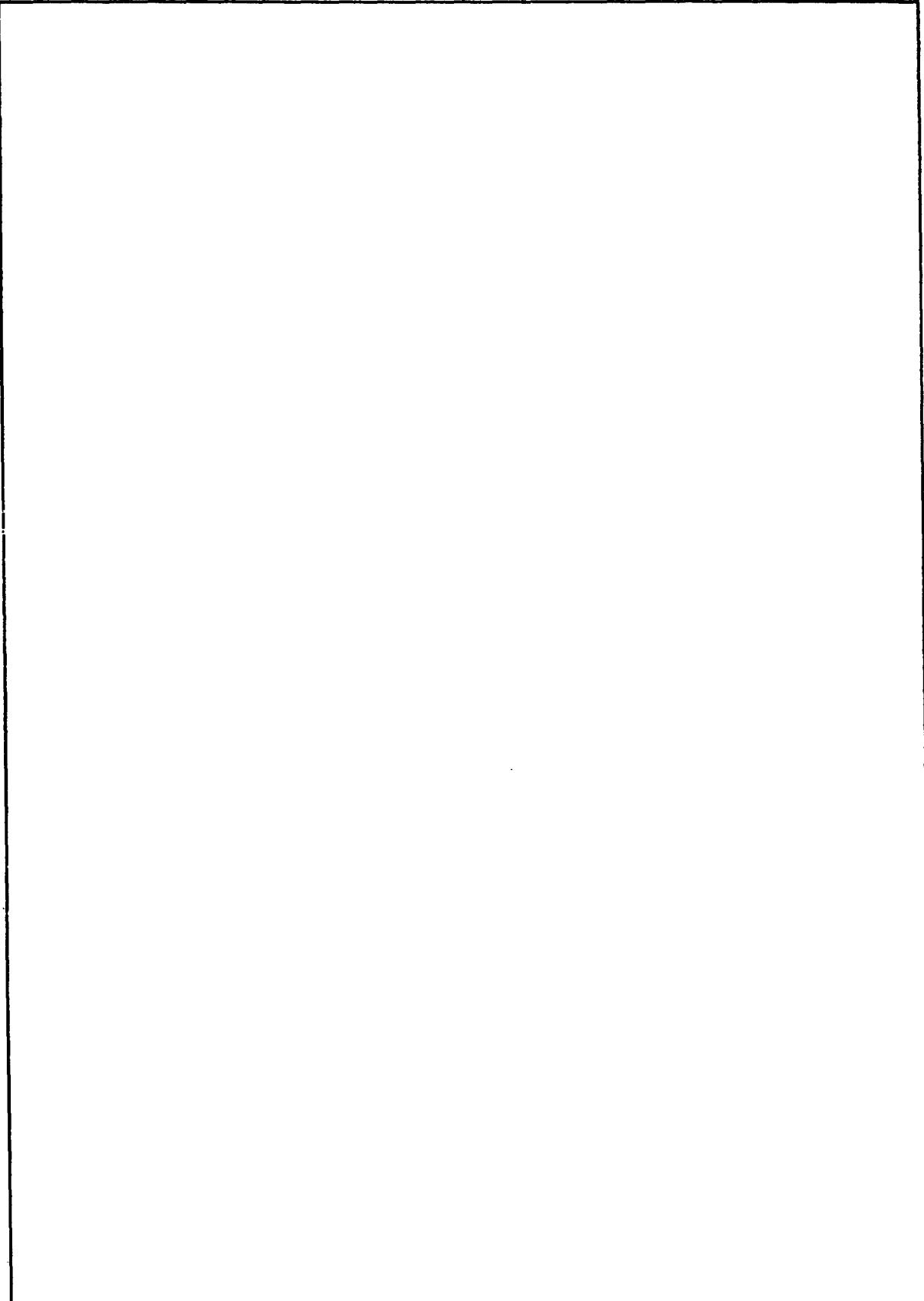


ROY L. DEHART
Colonel, USAF, MC
Commander

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)



SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

PREFACE

The authors are grateful to the people who contributed suggestions and criticisms during the development of this report. Special thanks are due to Richard L. Miller, Ph.D., and Mr. Clarence F. Theis, M.A., of the Crew Environments Branch, USAF School of Aerospace Medicine, Brooks AFB, Texas.

CONTENTS

| | <u>Page</u> |
|---|-------------|
| INTRODUCTION | 7 |
| USAFSAM SODIUM CHLORIDE RESPIRATOR QUANTITATIVE FIT TEST INSTRUMENT. . . | 10 |
| Aerosol Generation System | 10 |
| Aerosol Sampling System | 11 |
| Aerosol Detection System. | 11 |
| PREPARATION OF SODIUM CHLORIDE CHALLENGE-CALIBRATION STANDARDS | 32 |
| Preparation of the Glassware. | 32 |
| Preparation of the 5% Sodium Chloride Challenge Solution. | 33 |
| Serial Dilution Procedure | 34 |
| Preparation of the Sodium Chloride Nebulizers | 35 |
| CALIBRATION PROCEDURE. | 35 |
| DATA COLLECTION AND REDUCTION. | 37 |
| Protection Factor | 42 |
| Strip-Chart Recorder. | 42 |
| Voltage-to-Frequency Converter Electronic Integrator. | 46 |
| Data Collection | 58 |
| Computer Calculation. | 58 |
| OPERATION OF THE SODIUM CHLORIDE RESPIRATOR QUANTITATIVE FIT TEST INSTRUMENT. | 59 |
| "Start-up" Procedure | 59 |
| Hydrogen Flame Ignition | 59 |
| Integrator and Strip-Chart Recorder Preparation | 60 |
| Respirator Evaluation | 60 |
| "Shutdown" Procedure. | 61 |
| MAINTENANCE. | 68 |
| General Instrument Cleaning | 68 |
| Hydrogen Flame Photometer Jet Cleaning. | 70 |
| Photomultiplier Tube Replacement. | 70 |
| CONCLUSION | 70 |
| CITED REFERENCES | 70 |
| SUPPLEMENTAL REFERENCES. | 71 |
| ABBREVIATIONS, ACRONYMS, AND SYMBOLS | 72 |

FIGURES

| Fig. No. | Page |
|--|------|
| 1. Sodium chloride respirator quantitative fit test instrument (photograph) | 8 |
| 2. Sodium chloride respirator quantitative fit test instrument (schematic diagram). | 9 |
| 3-a. Sodium chloride respirator quantitative fit test instrument console (photograph) | 12 |
| 3-b. Sodium chloride respirator quantitative fit test instrument console (schematic diagram). | 13 |
| 4-a. Dautrebande nebulizer (photograph) | 14 |
| 4-b. Dautrebande nebulizer (schematic diagram). | 15 |
| 5. Respirator quantitative fit test instrument console (rear view). | 16 |
| 6-a,b. Respirator quantitative fit test instrument console (side view): | |
| a. Bypass tubing installed. | 17 |
| b. Bypass tubing removed. | 18 |
| 7-a. Plastic hood | 19 |
| 7-b. Test subject in flight suit and MBU-13/P respirator. | 20 |
| 7-c. Mechanical assembly for plastic hood displacement | 21 |
| 8-a. Aluminum sampling tube | 22 |
| 8-b. Test respirator (MBU-13/P) | 23 |
| 9-a. Metal-bellows pump | 24 |
| 9-b. Air-sampling system calibration. | 25 |
| 10. Sodium chloride respirator quantitative fit test instrument <u>electro-optic</u> processing scheme | 27 |
| 11. Sodium chloride respirator quantitative fit test instrument <u>electronic</u> processing scheme | 28 |
| 12. Current-to-voltage converter, low-pass filter, and logarithmic amplifier | 29 |

FIGURES (Cont'd.)

| <u>Fig. No.</u> | | <u>Page</u> |
|-----------------|--|-------------|
| 13. | Strip-chart recorder interface circuit | 30 |
| 14. | Transfer function plot relating PMT output current to strip-chart recorder voltage. | 31 |
| 15. | Strip-chart recorder | 38 |
| 16. | The voltage divider used to scale the PMT's bias to be compatible with the strip-chart's recorder input. | 39 |
| 17. | Integrator | 40 |
| 18. | Sodium chloride calibration-challenge concentrations vs. photomultiplier tube (PMT) output voltage | 41 |
| 19. | Sodium chloride respirator quantitative fit test strip-chart recording | 44 |
| 20. | Logarithmically scaled sodium chloride calibration data used to interpolate mask leakage concentration. | 45 |
| 21. | Operating principle of a voltage-to-frequency integrator . . | 47 |
| 22-a,b,c | Sodium chloride respirator quantitative fit test instrument integrator (schematic diagrams) | 50 |
| 23. | Sodium chloride respirator quantitative fit test instrument integrator digital display. | 53 |
| 24. | Sodium chloride respirator quantitative fit test instrument integrator voltmeter schematic | 54 |
| 25. | Internal functions of the Analog Devices AD450J voltage-to-frequency converter | 55 |
| 26. | Data collection sheet for 6-exercise protocol. | 62 |
| 27. | Data collection sheet for 16-exercise protocol | 63 |
| 28. | Respirator quantitative fit test instrument power supply . . | 64 |
| 29. | Line air pressure gauge and control. | 65 |
| 30. | Respirator quantitative fit test instrument flowmeters . . | 66 |

FIGURES (Cont'd.)

| <u>Fig. No.</u> | | <u>Page</u> |
|-----------------|--|-------------|
| 31. | Two-stage hydrogen pressure regulator. | 67 |
| 32. | Respirator quantitative fit test instrumentation, as the time and the integrator count for each exercise are being recorded. | 69 |

TABLES

Table No.

| | | |
|----|---|----|
| 1. | Sodium chloride challenge-calibration standard solutions | 35 |
| 2. | Sodium chloride standard calibration voltages. | 37 |
| 3. | Penetration values and protection factors. | 43 |
| 4. | Major components of the voltage-to-frequency converter electronic integrator | 48 |
| 5. | Electronic specifications of the Analog Devices AD450J voltage-to-frequency converter | 56 |

SODIUM CHLORIDE RESPIRATOR QUANTITATIVE FIT TEST INSTRUMENT

INTRODUCTION

The importance of training users to obtain the best possible fit of a respirator to their face is a serious concern in both governmental and civilian work environments. Users must understand the capabilities of the respective respirator they are required to wear, and the degree of protection they can expect from it. Most importantly, users must be confident that respirators can be fitted in a reproducible manner. The sodium chloride respirator quantitative fit test (RQFT) instrument is a reliable, practical, and functional means of fitting respirators [1]. The participating nations of the Air Standardization Coordinating Committee (ASCC) have recommended a sodium chloride quantitative fit test scheme to measure a respirator's protection factor (PF) afforded to the respiratory tract and eyes against chemical warfare (CW) agents in particulate, aerosol, or vapor form [7]. The USAF School of Aerospace Medicine (USAFSAM) has endorsed this agreement. The USAFSAM sodium chloride RQFT instrument is shown in Figure 1, and its major subsystems are schematically depicted in Figure 2.

The USAFSAM sodium chloride RQFT instrument is routinely used to evaluate the performance of aircrew and groundcrew CW respirators. Performance is quantified by calculating a metric known as a PF. A respirator PF is defined as the ratio of the ambient challenge atmosphere concentration external to the respiratory protective device to that of the sampled leakage concentration drawn from the interior of the respirator [2]. A respirator leak most often results from a poor face-to-facepiece seal or from improper construction of the respirator [4-6].

To accomplish an RQFT, a subject dons a respirator and, having passed a preliminary qualitative fit test, sits under a transparent plastic hood that is lowered to waist-level. A cloth collar is drawn snugly around the subject's waist, and a solid aerosol challenge concentration of sodium chloride is allowed to equilibrate inside the hood. The subject performs a series of breathing and head-movement exercises, during which a sample is continuously drawn from the interior oral-nasal compartment of the respirator. The sample is vaporized in a hydrogen flame photometer, and the concentration of sodium chloride that leaked into the respirator is determined by the response of the photomultiplier tube (PMT). A permanent record of the PMT's response is collected on a strip-chart recorder, and an electronic integrator is used to acquire the data to calculate a PF.

EDITOR'S NOTE: Available, on p. 72, is a selective list (plus definitions) of the "Abbreviations, Acronyms, and Symbols" used throughout this report.

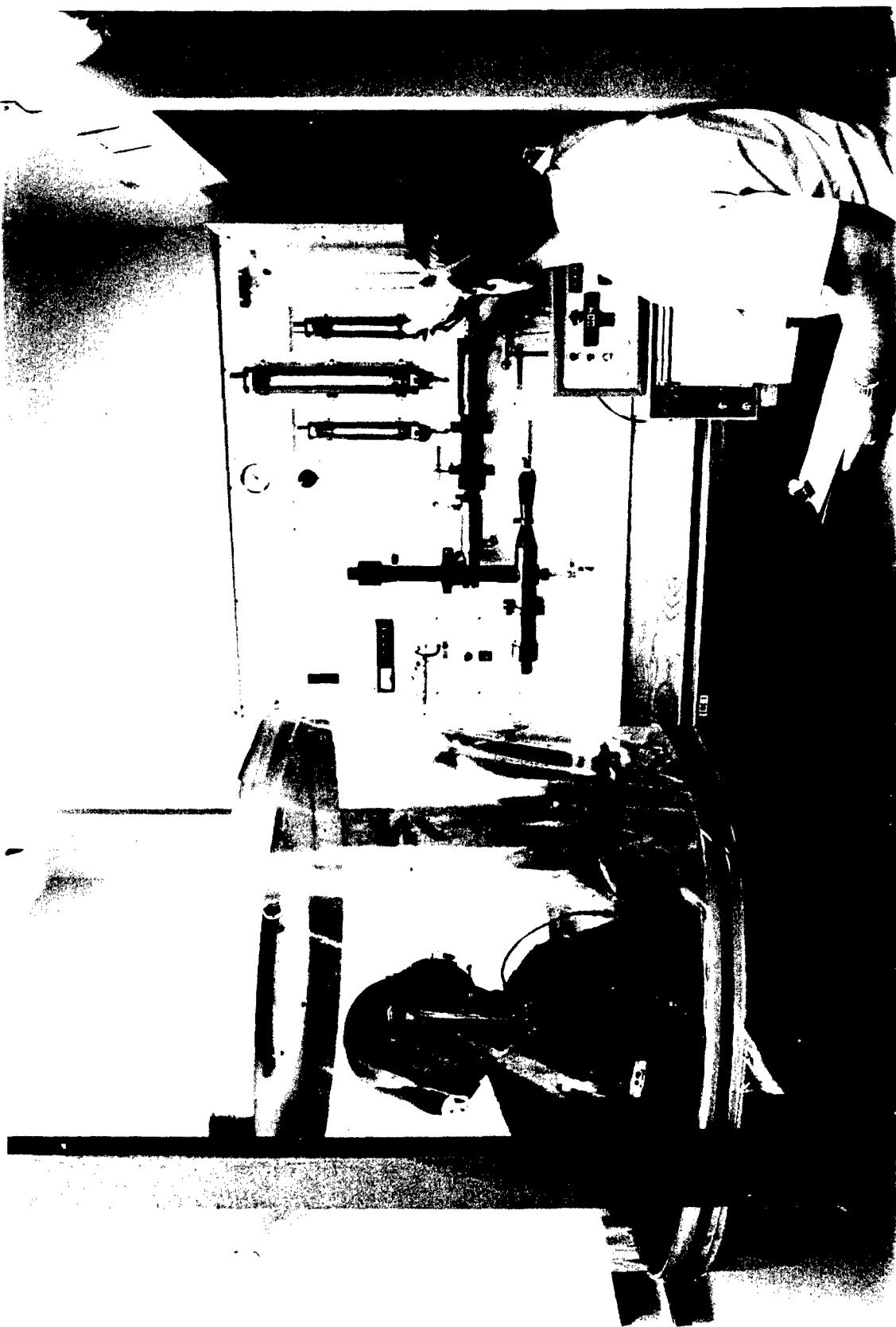


Figure 1. Sodium chloride respirator quantitative fit test instrument (photograph).

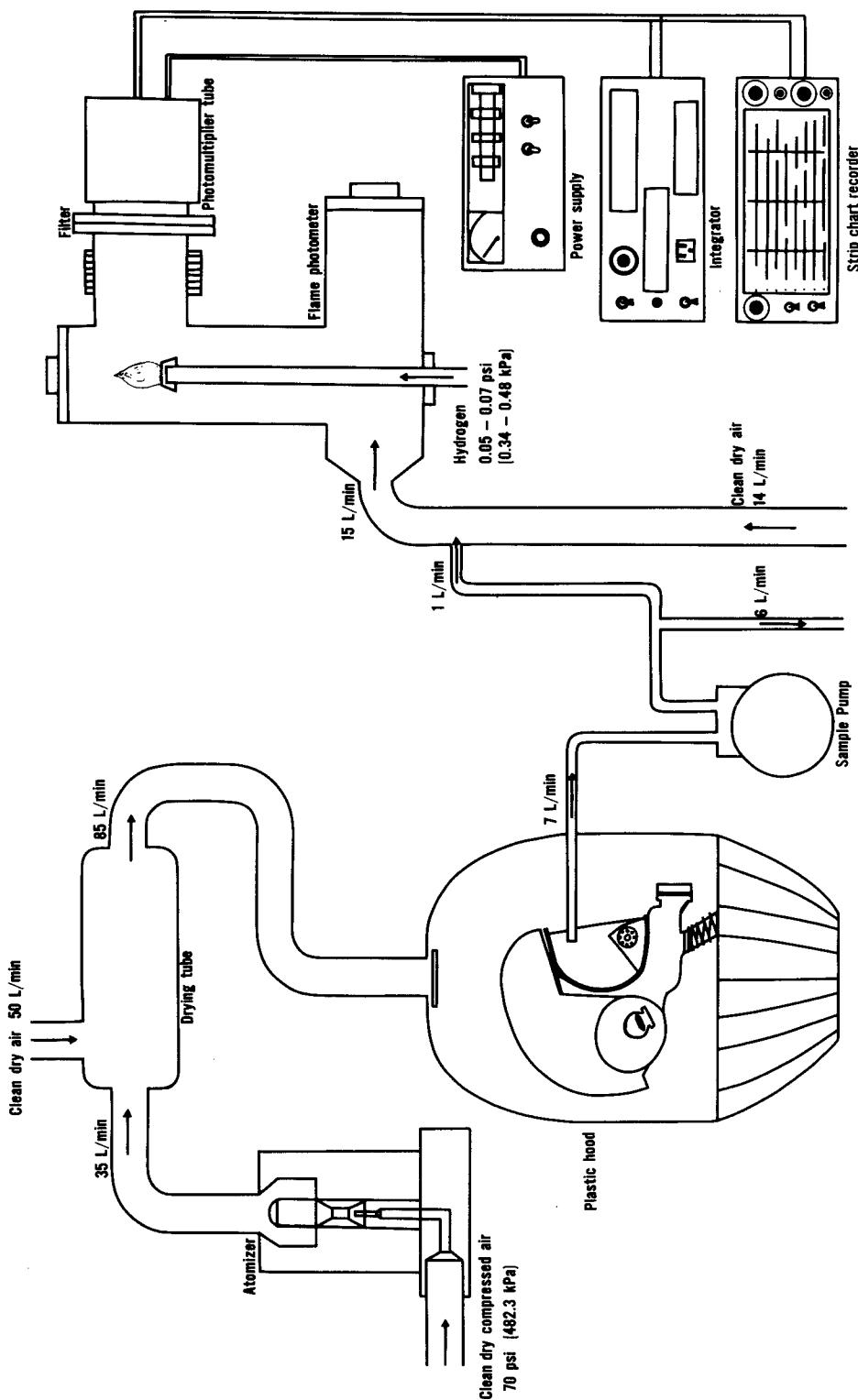


Figure 2. Sodium chloride respirator quantitative fit test instrument (schematic diagram).

USAFSAM SODIUM CHLORIDE RESPIRATOR QUANTITATIVE FIT TEST INSTRUMENT

This report discusses the sodium chloride RQFT instrument's aerosol generation, sampling, and detection subsystems. Critical to the operation of the sodium chloride RQFT instrument is the preparation of the sodium chloride challenge-calibration standards, hardware precalibration, and data collection and reduction. Finally, the step-by-step operation of the sodium chloride RQFT system and routine maintenance procedures are described.

Aerosol Generation System

A challenge atmosphere of dry sodium chloride particles is generated in the plastic hood by atomizing a 5% aqueous sodium chloride solution (10^0 calibration standard). The "LINE AIR PRESSURE CONTROL" (De Vilbiss Corporation, Model No. HAA-522 air regulator and Model No. HRE-501 oil and moisture separator, Toledo, OH 43692; and Ametek Incorporated, gauge, Part No. 37326, US Gauge Division, Sellersville, PA 18960) on the front console (Figs. 3-a and 3-b) is adjusted to 70 psi (482.3 kPa), thus producing a clean dry atomization air-supply flow of 35 liters/min (STP) to the Dautrebande nebulizer (Figs. 4-a and 4-b). A compressor (Colt Industries Incorporated, Model No. 32514, Quincy Compressor Division, Quincy, IL 62301) is utilized to generate the air supply; and a refrigerated air dryer (Colt Industries Incorporated, Model No. 8256, Quincy Compressor Division, Quincy, IL 62301) is used to filter and dry the air. The atomization air-supply flows through the nebulizer containing the 10^0 sodium chloride challenge solution, and produces a liquid aerosol. The "DRYING AIR" flowmeter (Fischer and Porter Company, Model 10A3555, Serial No. 7710A0367A17, Warminster, PA 18974) (Figs. 3-a and 3-b) is adjusted to its 85% setting, which yields a 50-liters/min (STP) flow of clean dry air to the mixing and drying tube (Figs. 3-b and 5). In the mixing and drying tube, the sodium chloride liquid aerosol is injected perpendicularly into the flow of drying air. The drying air evaporates water from the liquid aerosol and produces a solid aerosol sodium chloride challenge atmosphere. This atmosphere is composed of sodium chloride crystals having a mass-median aerodynamic diameter (MMAD) ranging from 0.4 to 0.6 μm . The sodium chloride challenge atmosphere is delivered to the plastic hood through a piece of Tygon tubing. The Tygon tubing, which is approximately 300 cm in length and 2.0 cm in diameter, connects the "SALT SOURCE OUTLET" (Fig. 6) on the side of the instrument console to the plenum, at the top center of the hood (Figs. 7-a and 7-b). A subject, having donned a respirator, sits on a chair located directly beneath the plastic hood (Fig. 7-b). The hood is lowered by means of the crank, cable, and pulley assembly (Fig. 7-c) to cover the subject's upper torso. The adjustable cloth collar (Fig. 7-a) attached to the bottom of the hood is drawn snugly around the subject's waist. The subject rests for 3 min, so that a uniform sodium chloride challenge atmosphere can equilibrate inside the hood [1,2,3]. After a stable challenge atmosphere is achieved, the operator directs the subject through an exercise protocol designed to simulate work-environment activities.

Aerosol Sampling System

While the subject performs a series of head movement and breathing exercises, an air sample is continuously drawn from the oral-nasal compartment of the respirator. An aluminum sampling tube (Fig. 8-a), approximately 2.5 cm in length and 0.6 cm in diameter, is fitted through--and sealed to--the respirator's visor so that the distance from the cornea to the open end of the tube interior to the visor is not greater than 2 cm. A length of Tygon tubing with a diameter of approximately 0.6 cm is attached to the aluminum sampling tube exterior to the respirator's visor (Fig. 8-b). The other end of the Tygon tubing is passed through a sealed port in the top of the transparent plastic hood, and is connected to the "SAMPLE INLET" port (Fig. 6) on the side of the RQFT instrument's console. A metal-bellows, positive-displacement, continuously sampling pump (Metal Bellows Corporation, Model MB-21, Sharon, MA 02067) (Fig. 9-a) is connected to the "SAMPLE INLET" port with approximately 43 cm of Tygon tubing. This pump is used to draw a continuous air sample (7 liters/min) from the visual compartment of the respirator. A 6-liters/min portion of the air sample is bled to the ambient atmosphere through a calibrated orifice (Fig. 9-b). As shown in Figure 2, the remaining 1-liter/min air sample is diluted with a 14-liters/min flow of clean dry compressed air, and injected into the hydrogen flame photometer for analysis. The dilution airflow (14 liters/min) is regulated with the "Sample Carrier Air" (Figs. 3-a and 3-b) flowmeter (Fischer and Porter Company, Model 10A3555, Serial No. 7710A0367A12, Warminster, PA 18974).

The 7-liters/min sampling rate was selected; for it minimizes the negative pressure created within the respirator's visual compartment, yet allows the pump to draw the air sample at a constant steady flow. The 15-liters/min sample and dilution-air mixture was selected, because it yielded optimum performance from the hydrogen flame photometer [1,2,3].

Aerosol Detection System

Detection of sodium chloride aerosol that has leaked into the interior compartment of a respirator is accomplished with a hydrogen flame photometer (Figs. 2 and 3-b). The hydrogen flame burner is used to vaporize the sodium chloride crystals. Hydrogen was selected as a combustion gas because of its pure, almost colorless (pale blue) flame. A hydrogen pressure control valve (Fig. 3-b) is adjusted to regulate the hydrogen flow to 0.05 - 0.07 psi (0.34 - 0.48 kPa). This setting produces a 2.5-cm vertical flame.

An optical bandpass filter (Instrumentation Laboratory, Part No. 24126-08, Lexington, MA 02173) (Figs. 2 and 3-b), sensitive to a 589 nanometer (nm) wavelength, is used to detect the strong yellow sodium emission line and reject other stray light emissions [2,3]. The relative intensity of the filtered yellow sodium emission light is detected with a PMT (International Telephone and Telegraph [ITT], Model No. FW130, Electro-Optical Products Division, Roanoke, VA 24019).

Since the PMT's output current is directly proportional to the intensity of the yellow light impinging upon its cathode, and the intensity of the yellow light is directly proportional to the concentration of the sodium chloride in the vicinity of the hydrogen flame, the PMT's output current is directly proportional to the sodium chloride concentration sampled from the interior of the respirator [2].

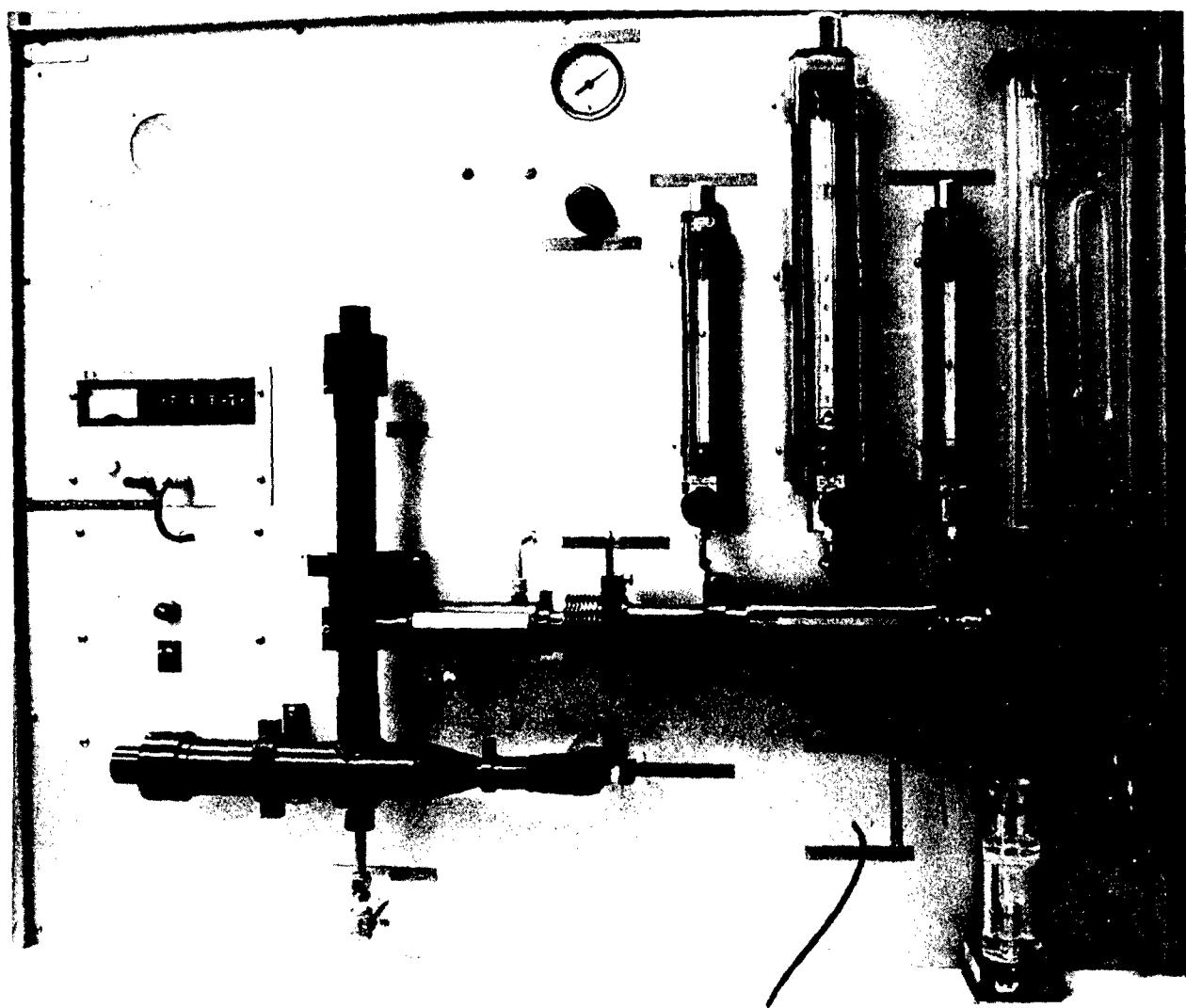


Figure 3-a. Sodium chloride respirator quantitative fit test instrument console (photograph).

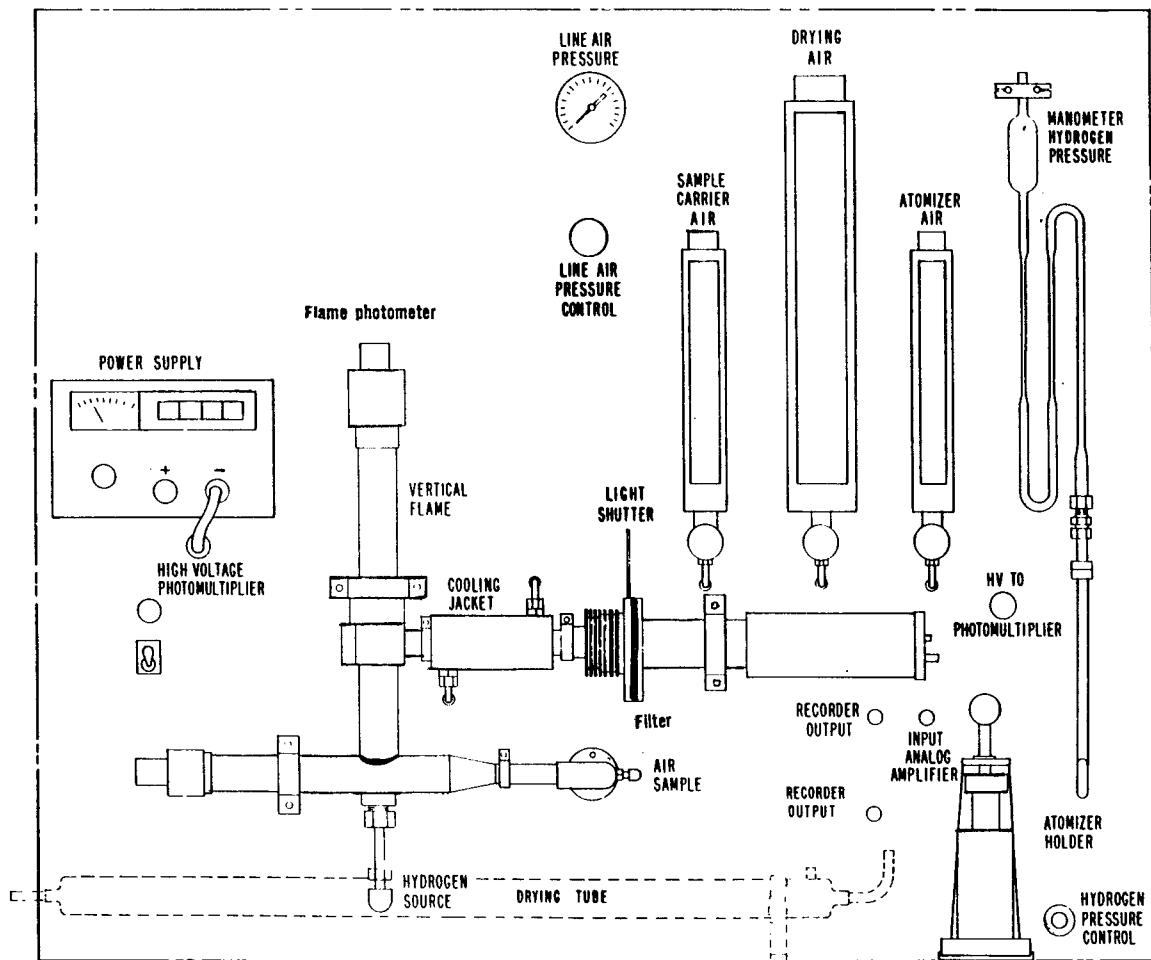


Figure 3-b. Sodium chloride respirator quantitative fit test instrument console (schematic diagram).

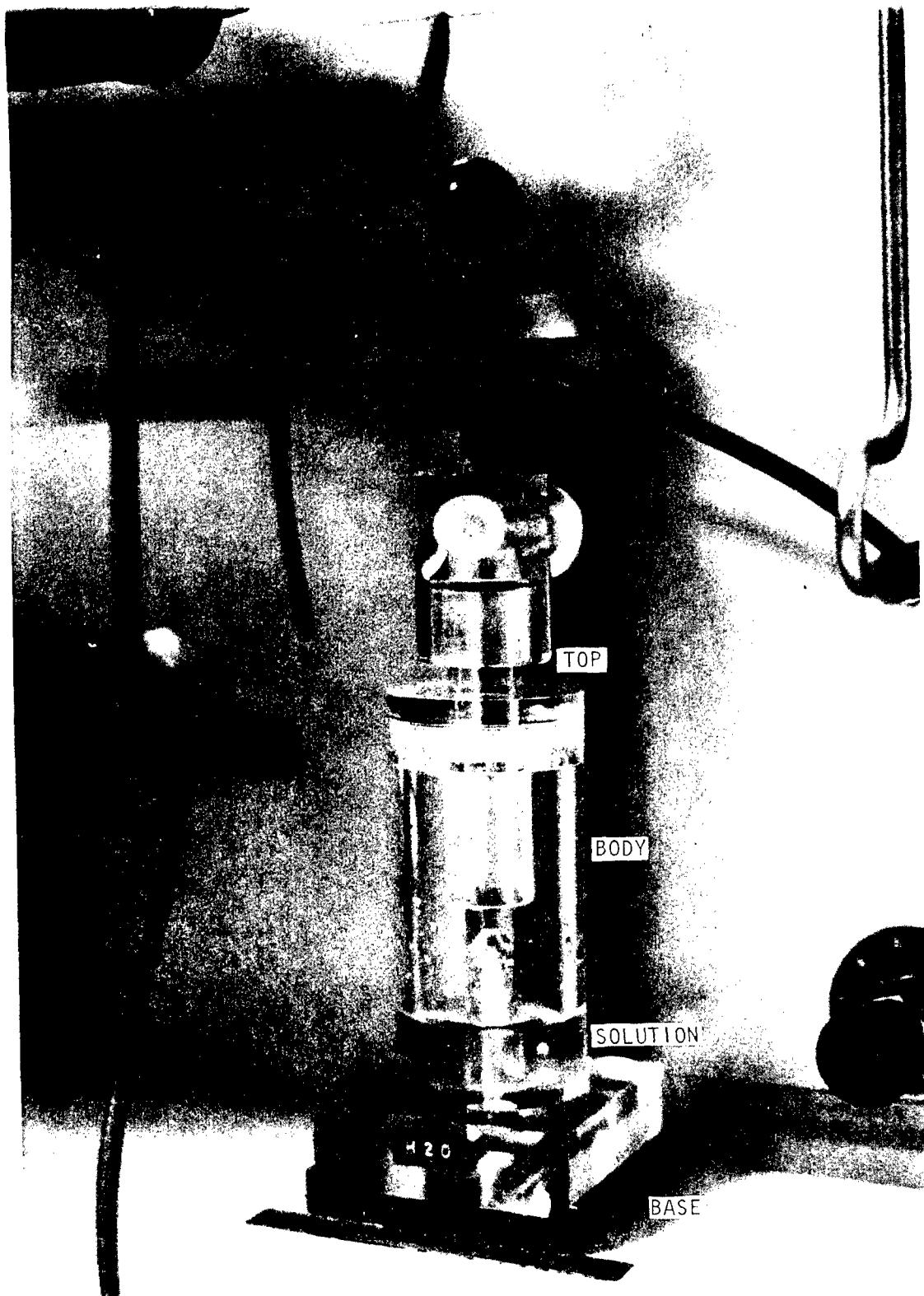


Figure 4-a. Dautrebande nebulizer (photograph).

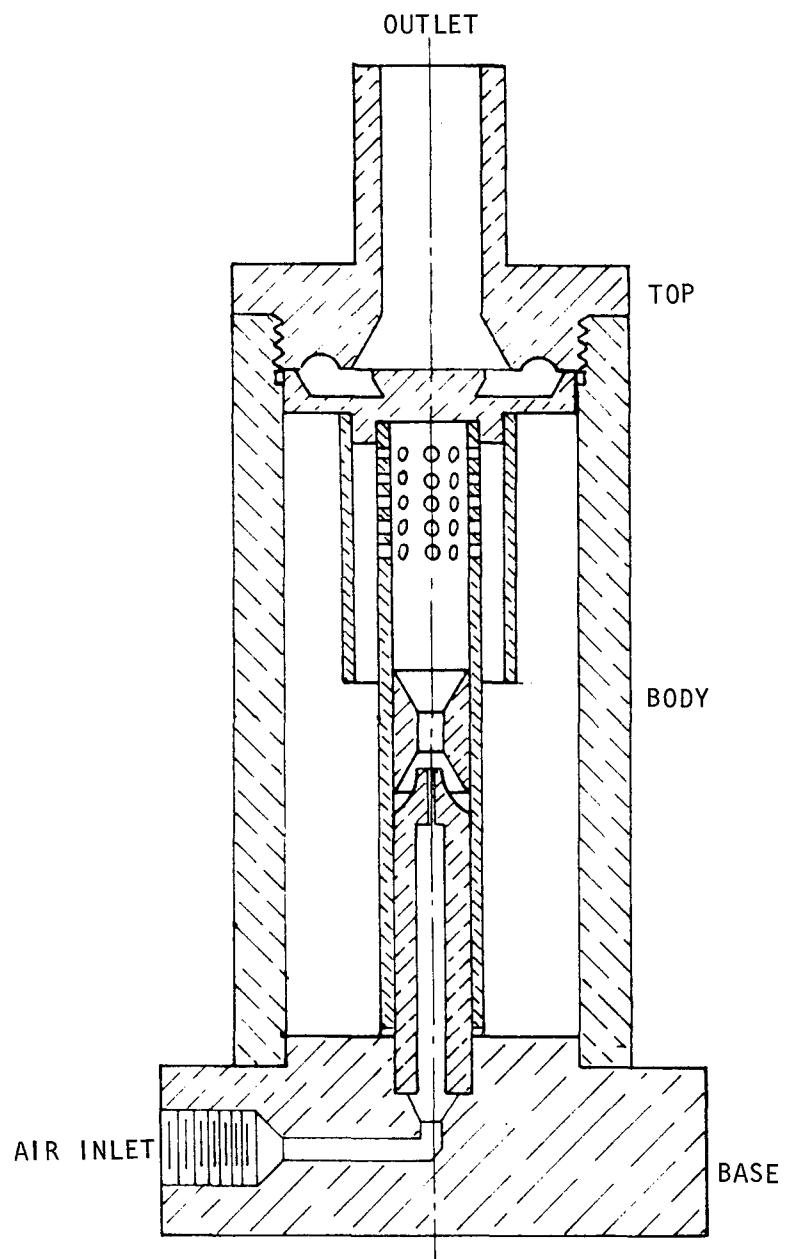


Figure 4-b. Dautrebande nebulizer (schematic diagram).

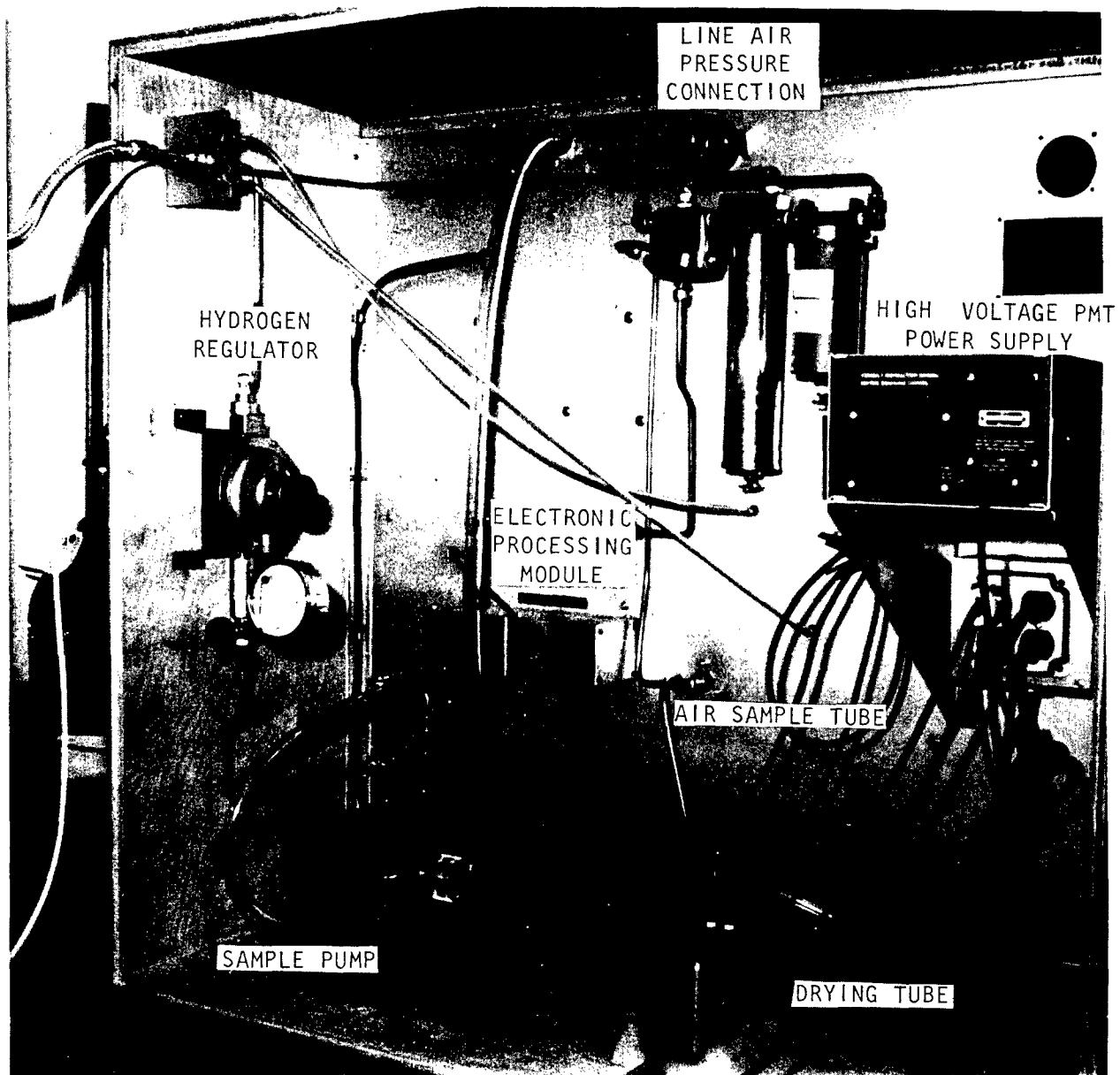
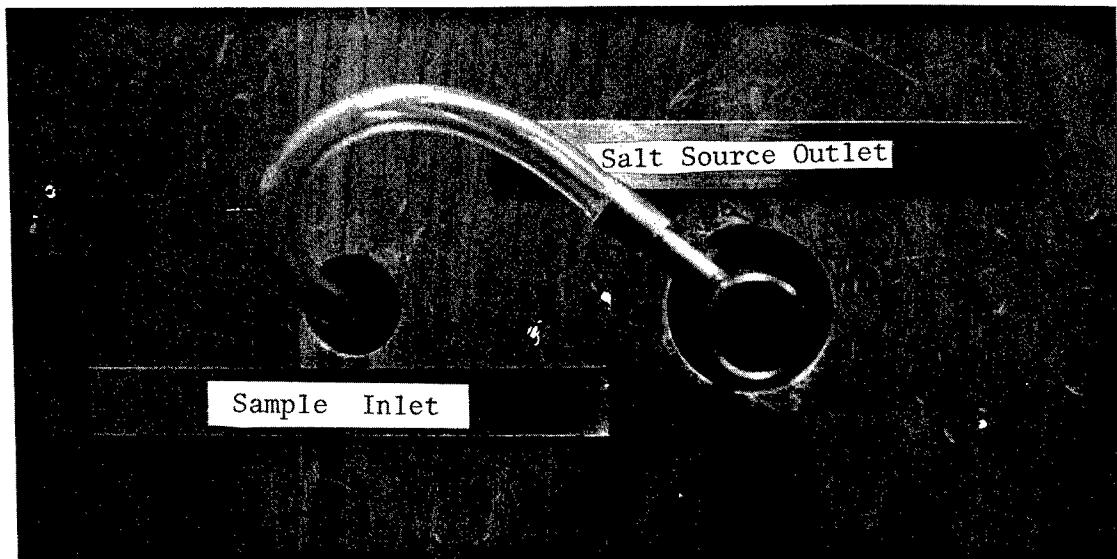


Figure 5. Respirator quantitative fit test instrument console (rear view).

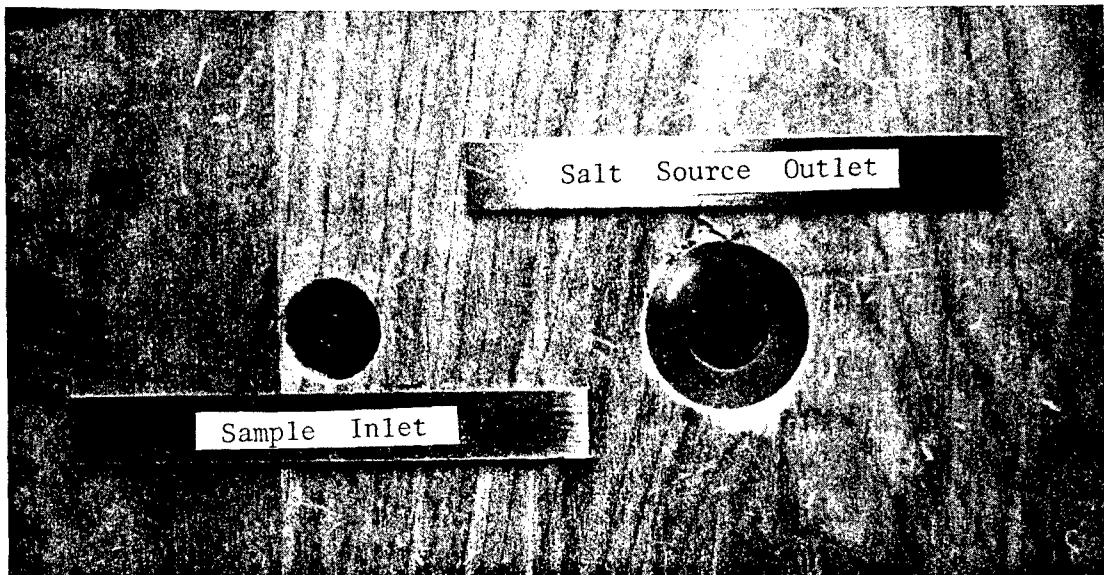


View a: Bypass tubing installed.

Figure 6 (a and b). Respirator quantitative fit test instrument console (side view).

[For view b, refer to next page.]

(Fig. 6, Cont'd.)



View b: Bypass tubing removed.

Figure 6 (a and b). Respirator quantitative fit test instrument console (side view).

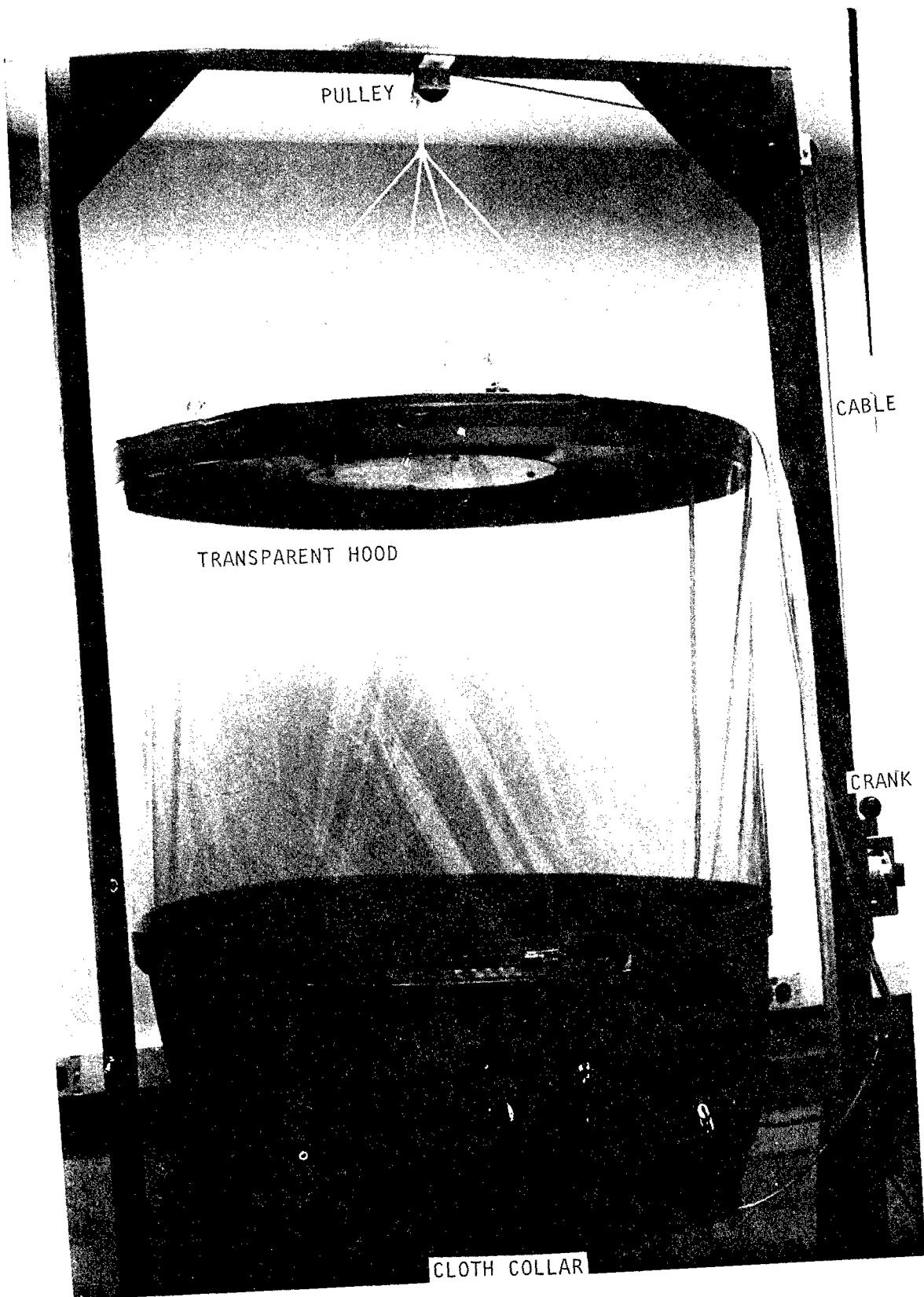


Figure 7-a. Plastic hood.



Figure 7-b. Test subject in flight suit and MBU-13/P respirator.

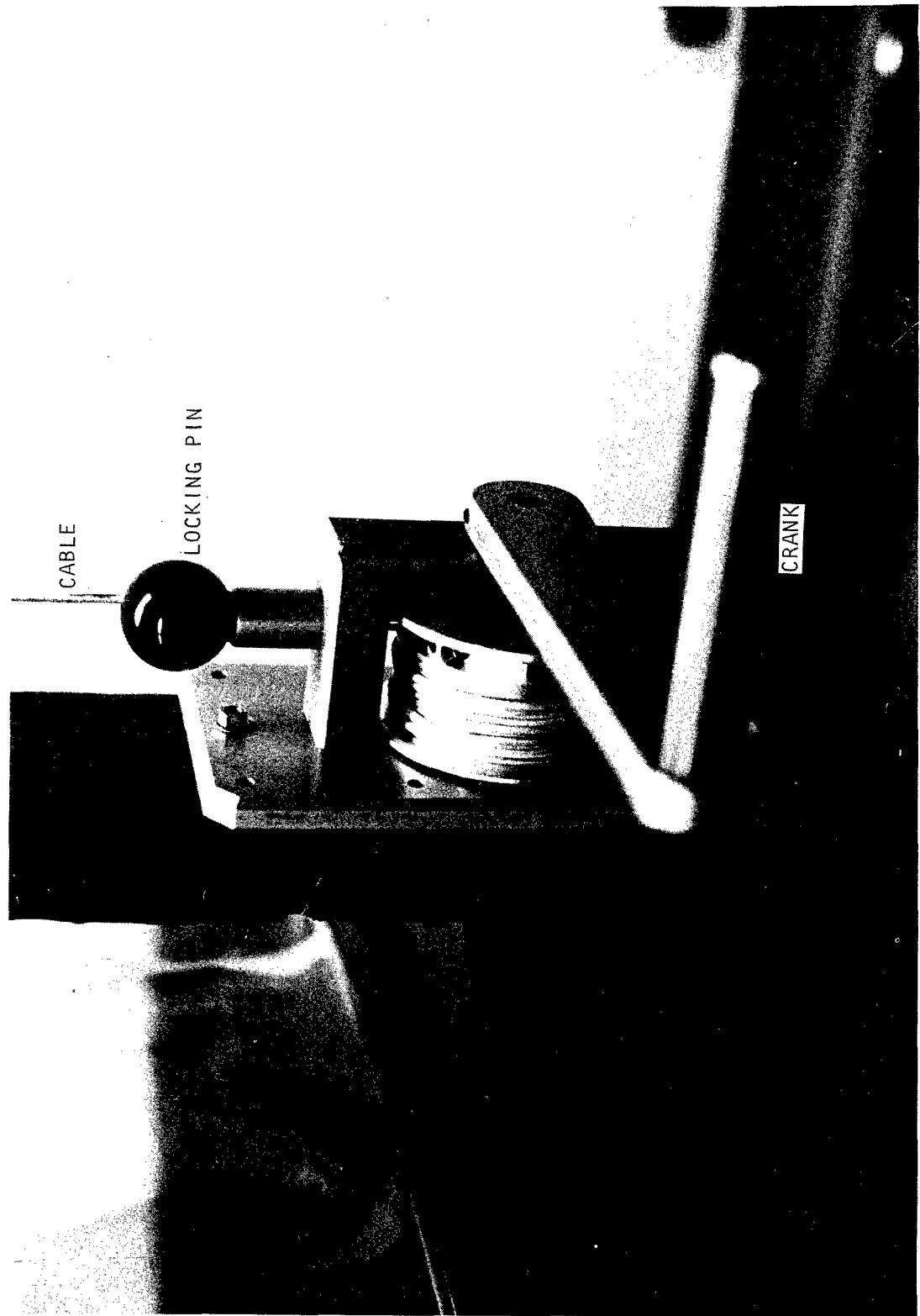


Figure 7-c. Mechanical assembly for plastic hood displacement.

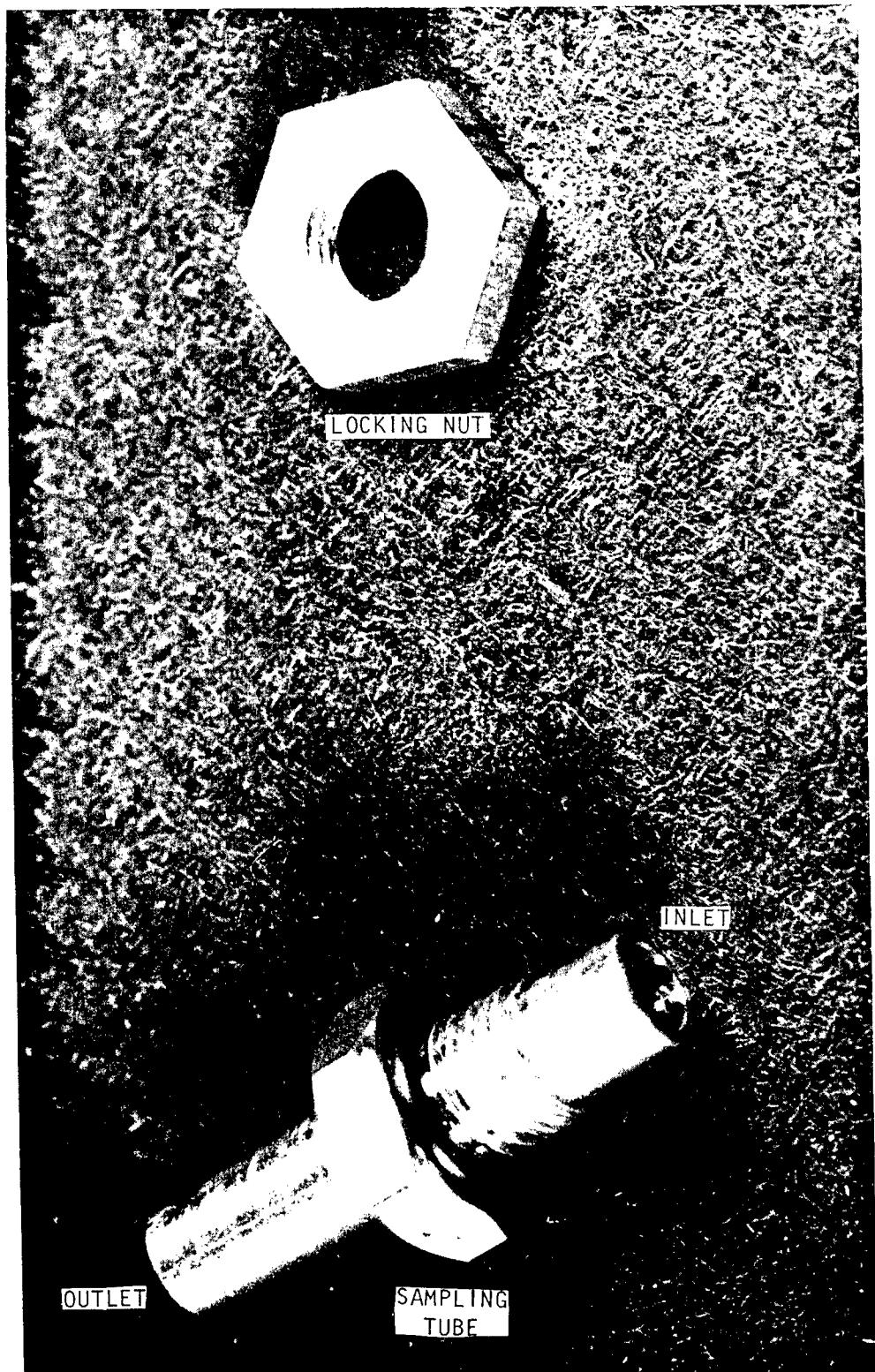


Figure 8-a. Aluminum sampling tube.



Figure 8-b. Test respirator (MBU-13/P).

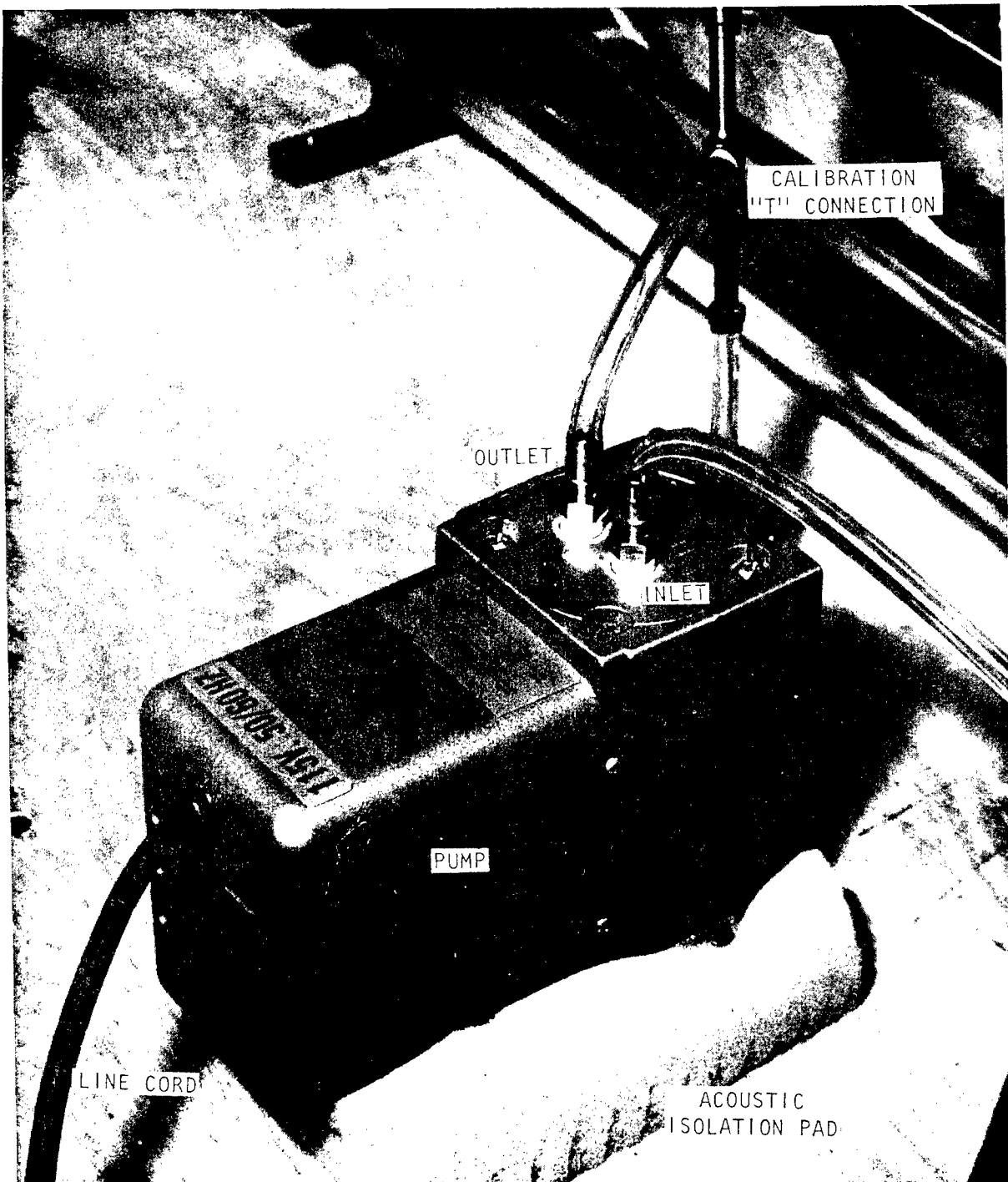


Figure 9-a. Metal-bellows pump.

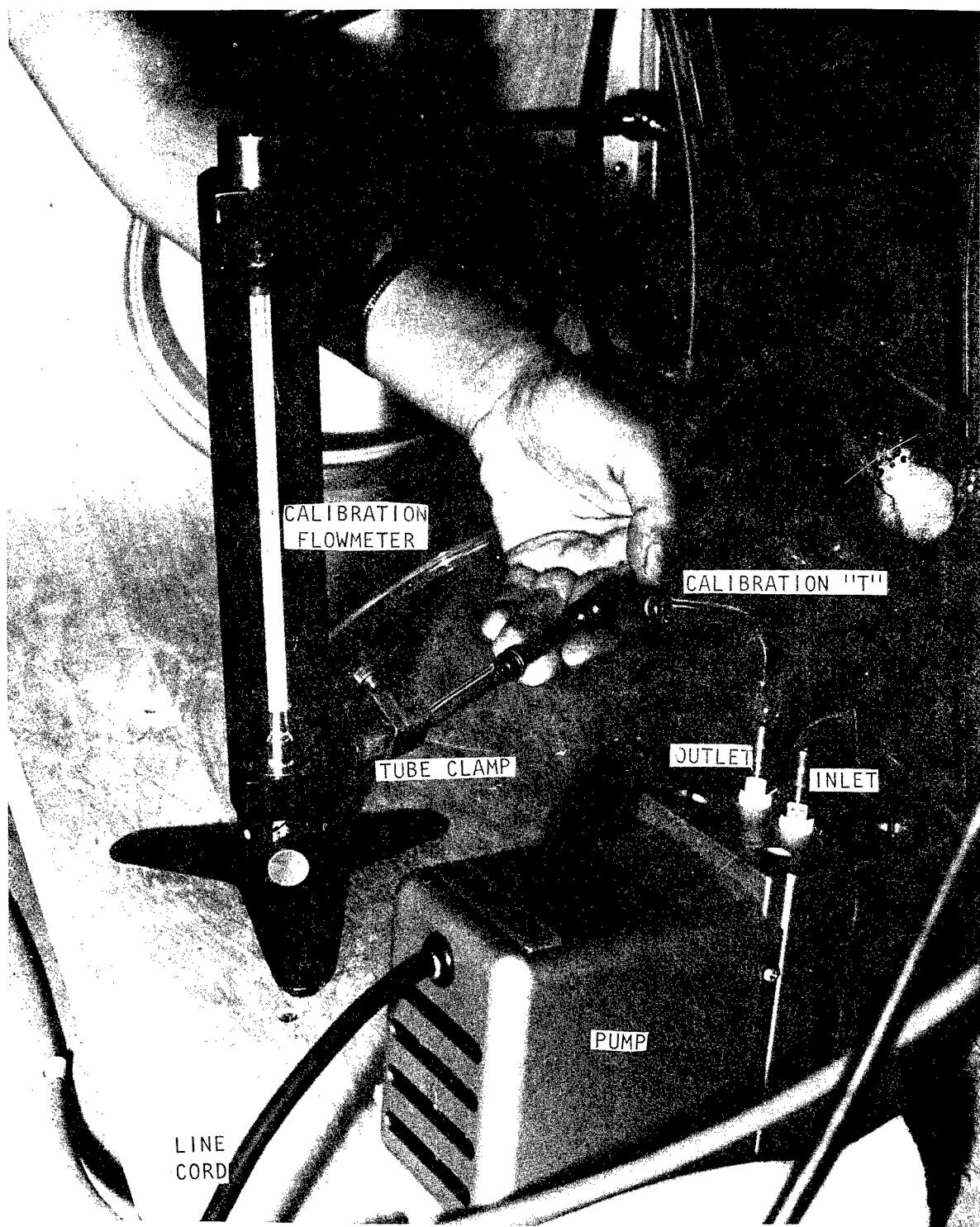


Figure 9-b. Air-sampling system calibration.

The electro-optic scheme used to quantify a respirator's sodium chloride leakage is diagrammed in Figure 10 [2,3].

The PMT's output current is electronically processed; and the result is displayed on a strip-chart recorder (Hewlett-Packard, Model No. 7100B, Palo Alto, CA 94304). During electronic processing, the PMT's output current is [2,3]:

1. filtered to reduce random high-frequency noise components;
2. converted to a voltage that can be displayed on a strip-chart recorder; and
3. scaled logarithmically to accommodate four orders of current magnitude on a single-span 0- to 5-V strip-chart recorder.

The sodium chloride RQFT electronic processing scheme is diagrammed in Figure 11 [2,3]. An integrated circuit (Harris Semiconductor Corporation, Model No. HA2-2905-5, Melbourne, FL 32901) is used in a current-to-voltage conversion scheme; another integrated circuit (Analog Devices Corporation, Model No. 755N, Norwood, MA 02062) is used in the logarithmic amplifier design; and an operational amplifier integrated circuit (Signetics Corporation, Model No. 741, Sunnyvale, CA 94086) is used in the interface circuit that drives the strip-chart recorder [2]. Shown in Figure 12 is a schematic diagram of the current-to-voltage converter, low-pass filter, and logarithmic amplifier. Figure 13 illustrates the electronics associated with the strip-chart recorder interface circuit [2,3].

The ITT special-purpose, 16-stage, electrostatically focused PMT, used as the detector (Figs. 2 and 3-b), is nominally operated with an anode-to-cathode potential between 1300 and 2200 V [3]. Under these operating conditions, the PMT's dark-current response is approximately 100 times less than the PMT's background current (PMT background current is defined as: the current produced by the detector when the hydrogen flame is surrounded by a medium free of sodium chloride). The following transfer function relates the PMT's output current to the strip-chart recorder voltage [2,3]:

$$v = 2 + \log_{10} \left[\frac{I}{1.1 \mu A} \right] \quad (1)$$

in which v = output voltage to strip-chart recorder, in volts; and
 I = PMT output current in microamperes.

This transfer function is graphically illustrated in Figure 14 [2,3]. The PMT's output current varies over four decades; its minimum value is 11 nanoamperes (nA), and its maximum is 110 microamperes (μA). The current-to-voltage electronic circuit (Fig. 12) transforms this current to a voltage (0 - 4 V) compatible with the strip-chart recorder. Thus, 1-V output change occurs per decade of input current change [2,3].

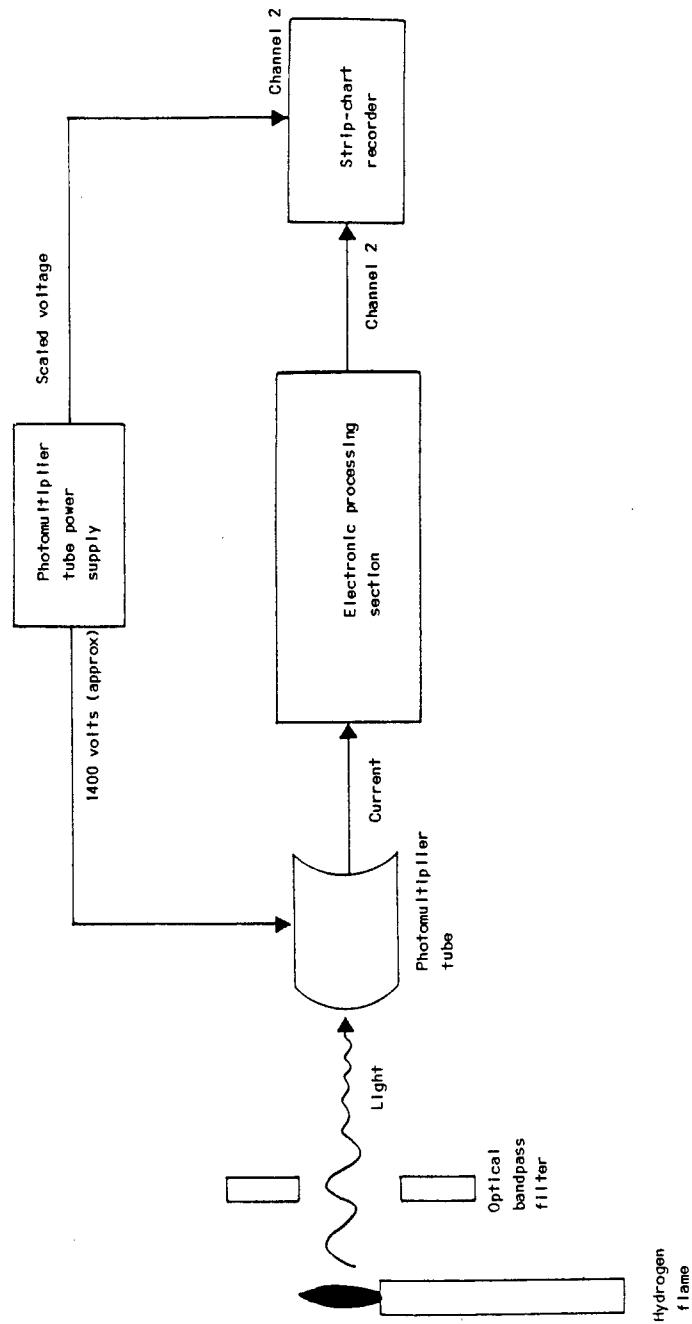


Figure 10. Sodium chloride respirator quantitative fit test instrument electro-optic processing scheme.

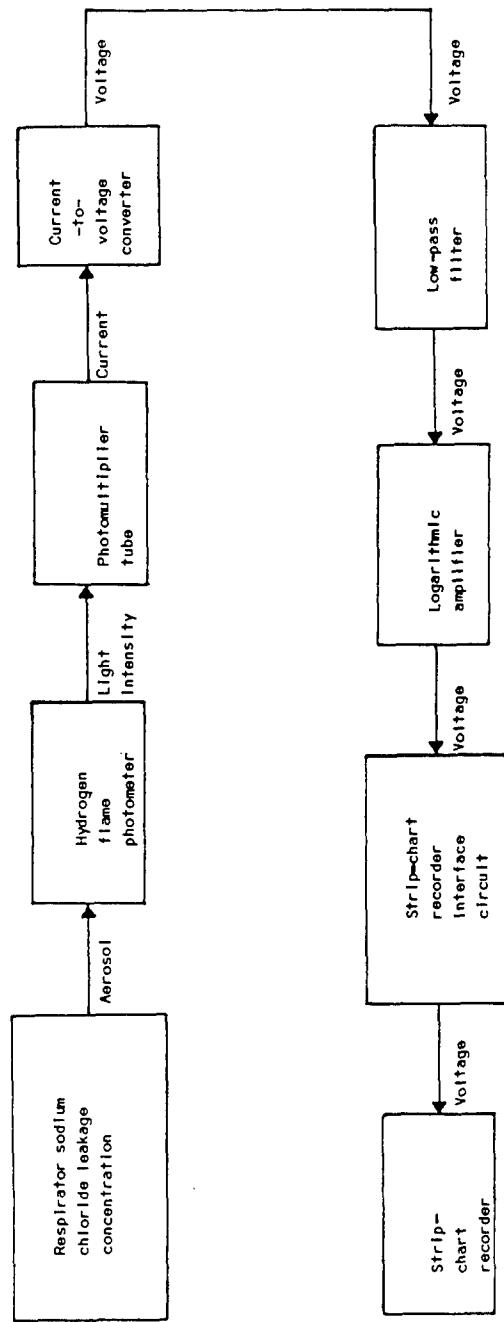


Figure 11. Sodium chloride respirator quantitative fit test instrument electronic processing scheme.

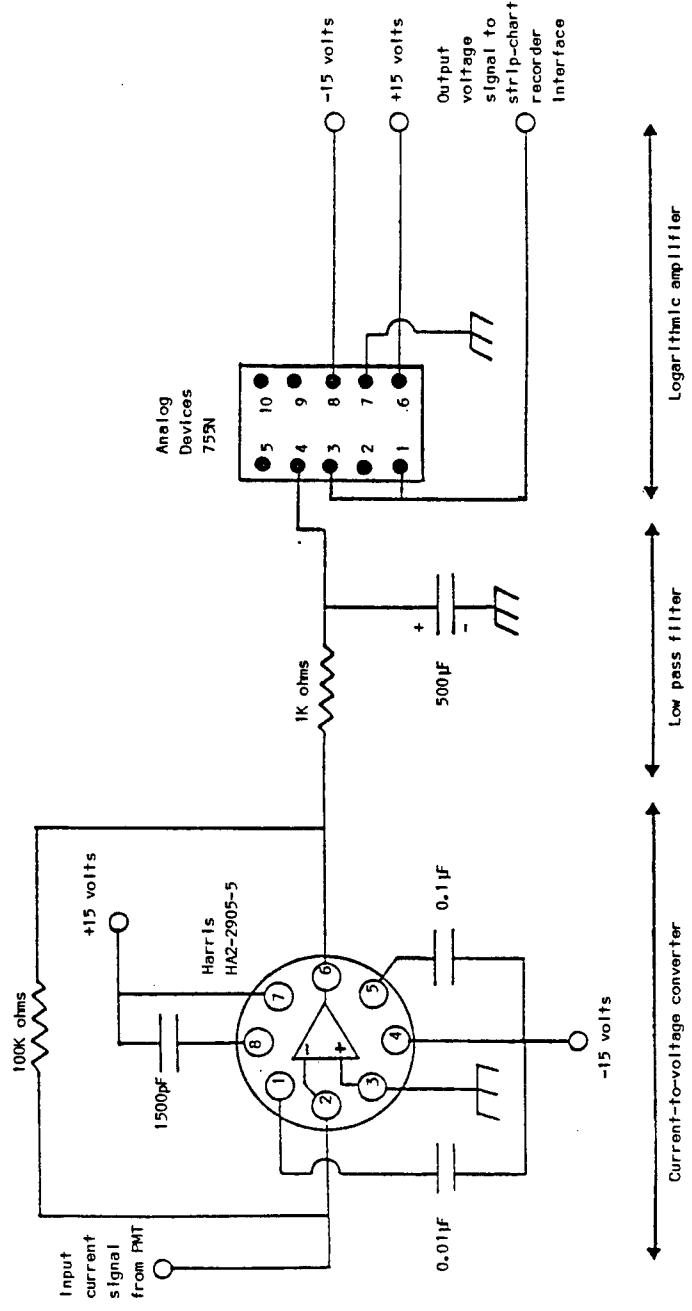


Figure 12. Current-to-voltage converter, low-pass filter, and logarithmic amplifier.

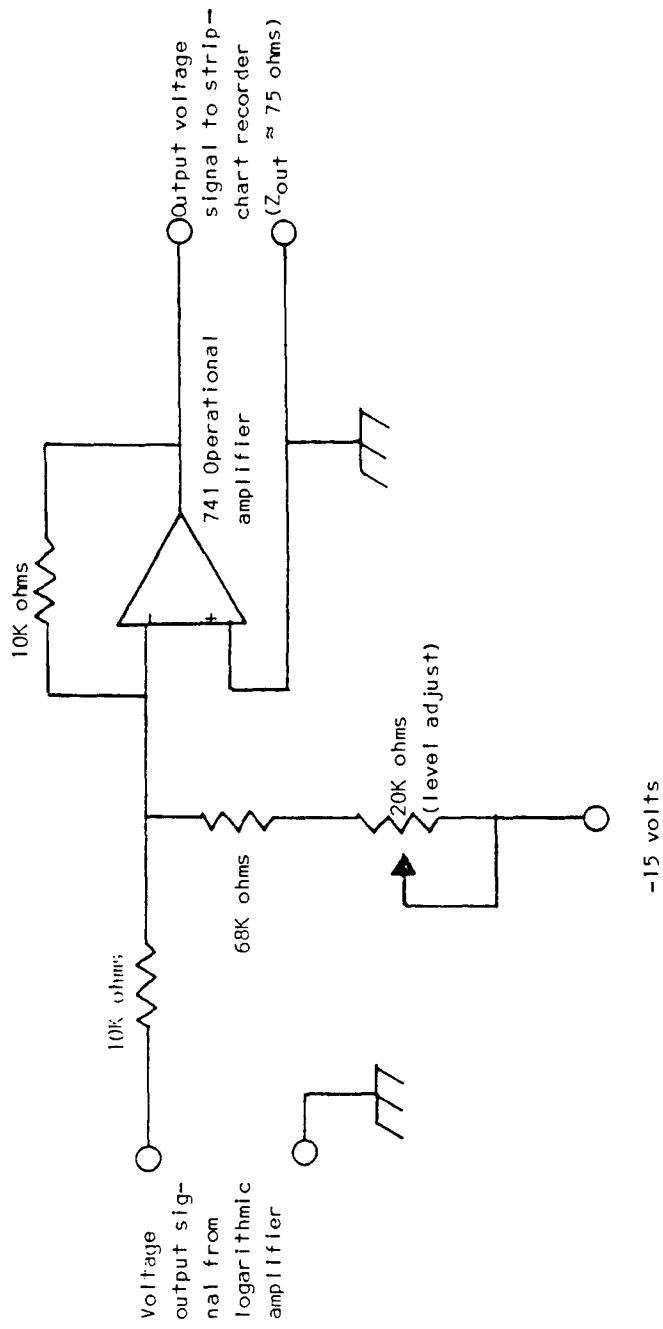


Figure 13. Strip-chart recorder interface circuit.

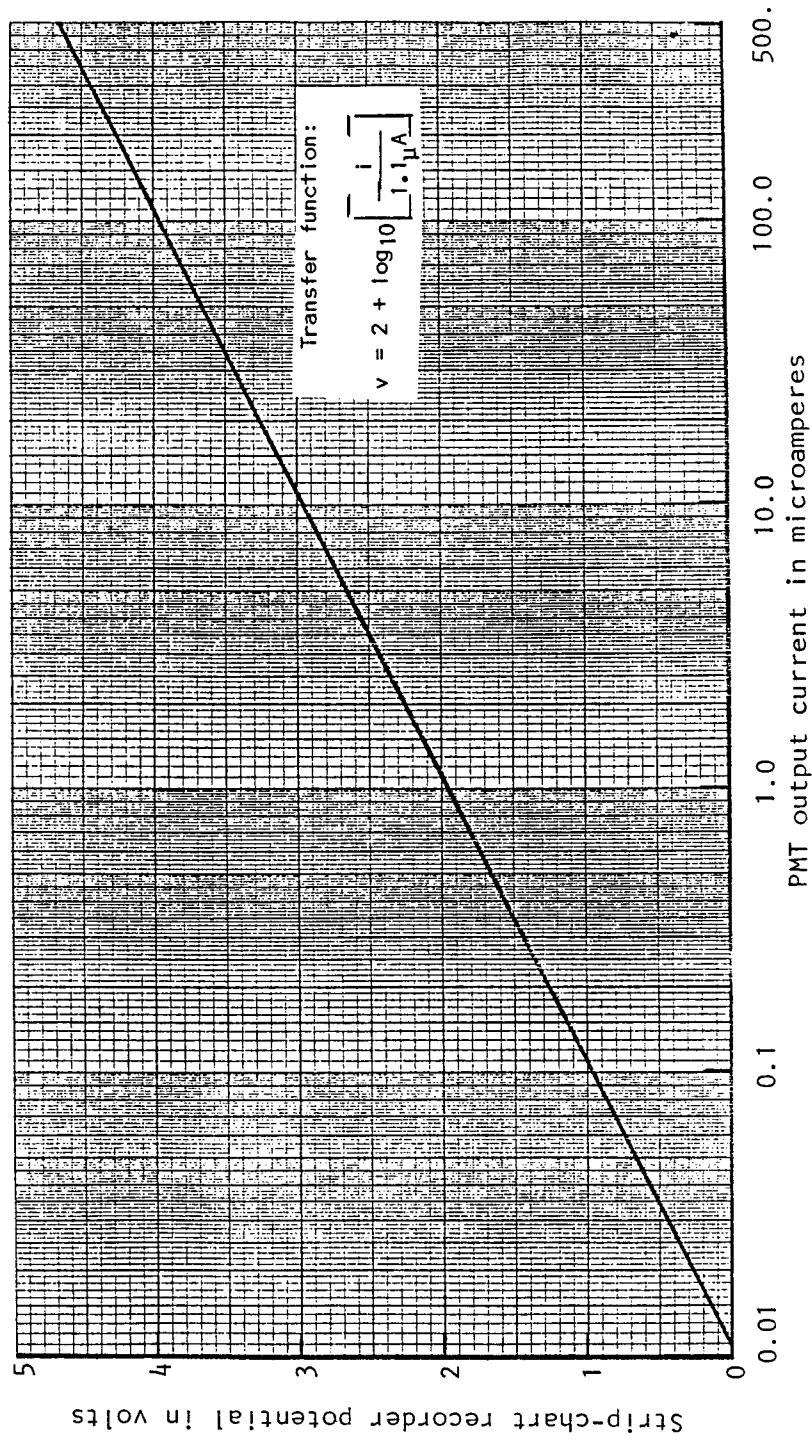


Figure 14. Transfer function plot relating PMT output current to strip-chart recorder voltage.

PREPARATION OF SODIUM CHLORIDE CHALLENGE-CALIBRATION STANDARDS

The set of sodium chloride calibration standards are prepared using the serial dilution method. The 5% sodium chloride challenge solution is used as the starting solution to produce the six calibration standards; these solutions are then used to measure respirator leaks that correspond to PF's ranging from 10^6 through 10^0 . The serial dilution method is quite simple, but specific guidelines must be followed to obtain consistent results [3]:

1. Use only class-A laboratory glassware.
2. Wash all glassware with 10% reagent grade nitric acid, triple rinse with glass-distilled or triple-deionized water, and air-dry thoroughly.
3. Use only analytical reagent grade chemicals.
4. Weigh and measure accurately.
5. Store all glassware and liquids at room temperature (20°C).

The equipment and reagents required are [3]:

1. seven 1000-ml class-A volumetric flasks with ground-glass stoppers;
2. six 100-ml class-A volumetric transfer pipettes;
3. seven nebulizers;
4. analytical balance with a guaranteed sensitivity of 0.1 mg;
5. aluminum weighing dish;
6. small stream laboratory wash bottles;
7. 1000-ml glass beaker;
8. sodium chloride (analytical reagent grade NSN 6810-00-234-8370);
9. concentrated reagent grade nitric acid; and
10. glass-distilled or triple-deionized water.

Preparation of the Glassware

All glassware must be acid-washed, triple-rinsed with glass-distilled or triple-deionized water, and thoroughly air-dried. The following procedures should be used to acid-wash the glassware [3]:

1. To prepare the 10% nitric acid solution, select a 1000-ml volumetric flask, add 900 ml distilled water, carefully add 100 ml concentrated nitric acid, and mix thoroughly.

2. Transfer approximately 50 ml of the acid solution to each flask.
3. Rotate the flask to coat the inner surfaces thoroughly, and discard the solution.
4. Rinse each pipette with nitric acid solution, and then rinse 3 times with distilled water.
5. Rinse each flask 3 times with 50 ml distilled water.
6. Place the flasks (in the inverted position) and pipettes on a clean absorbent surface to drain and air-dry.
7. If the glassware is to be stored, wrap it tightly with clean paper towels.
8. If the glassware has been stored, rinse it with distilled water and air-dry before using.

Preparation of the 5% Sodium Chloride Challenge Solution

Accurate weights and measures must be used to prepare the 5% sodium chloride challenge solution. This solution is prepared as follows [3]:

1. Accurately tare an aluminum weighing dish to the nearest 0.1 mg, and record the weight.
2. Add sodium chloride that has been thoroughly dried in a desiccator until the balance reads 50.000 g more than the tare weight of the dish.
3. Transfer the sodium chloride into a 1000-ml volumetric flask; and, with distilled water, rinse any residual crystals from the dish into the flask.
4. Add approximately 900 ml distilled water, and gently swirl the flask until all the sodium chloride crystals are dissolved.
5. Add additional distilled water until the solution is within 0.5 in. (1.27 cm) of the 1000-ml line on the flask's neck.
6. Continue to add distilled water, drop-wise, until the bottom of the solution meniscus touches the 1000-ml line on the flask.
7. Firmly place a ground-glass stopper in the neck of the flask.
8. Hold the stopper in place with your index finger, grasp the neck of the flask firmly with your thumb and remaining fingers, and carefully invert the flask.
9. Shake the flask, and return it to its upright position.

10. Repeat the inversion and the mixing process 3 times, or until the sodium chloride is dissolved.
11. Label the flask " 10^0 "; it will be used for the first serial dilution.

Serial Dilution Procedure

Six sodium chloride calibration standards are prepared using the following serial dilution method [3]:

1. Aspirate approximately 10 ml of the 10^0 standard solution into a 100-ml volumetric pipette.
2. Coat the inner surfaces of the pipette and discard the liquid.
3. Repeat twice, steps (1) and (2).
4. Fill the pipette with the 10^0 standard solution until it is 0.5 in. (1.27 cm) above the calibration line. (During this step, keep the tip of the pipette 1 in.--2.54 cm--below the surface of the sodium chloride solution).
5. Adjust the bottom of the meniscus to the pipette's calibration line using finger pressure.
6. Wipe any excess sodium chloride solution off the pipette barrel, but do not touch the tip.
7. Empty the pipette into a 1000-ml volumetric flask.
8. Add approximately 900 ml of distilled water to the flask, and gently swirl its contents to ensure a uniform mixture.
9. Add additional distilled water until the solution is 0.5 in. (1.27 cm) below the 1000-ml line on the flask's neck.
10. Continue to add distilled water, drop-wise, until the bottom of the meniscus touches the 1000-ml line on the flask.
11. Use inversion technique, already described in the report section on the "Preparation of 5% sodium chloride challenge solution," to mix contents of flask.
12. Label this flask " 10^{-1} ."
13. Repeat the serial dilution procedure; but substitute the 10^{-1} standard calibration solution in place of the 10^0 challenge standard, and label the resulting standard calibration solution " 10^{-2} ."
14. Use the 10^{-2} flask to prepare the 10^{-3} standard calibration solution; and continue to repeat this process until the 10^{-6} standard solution has been prepared from the 10^{-5} flask.

As a result, 7 sodium chloride solutions are made (one 10^0 challenge standard, and six [10^{-1} through 10^{-6}] calibration solutions); and their respective compositions are summarized in Table 1.

TABLE 1. SODIUM CHLORIDE CHALLENGE-CALIBRATION STANDARD SOLUTIONS

| Challenge-calibration standard solution | Composition (g/liter NaCl) |
|--|-------------------------------|
| 10^0 (5% challenge) | 50.0000 |
| 10^{-1} | 50.0000×10^{-1} |
| 10^{-2} | 50.0000×10^{-2} |
| 10^{-3} | 50.0000×10^{-3} |
| 10^{-4} | 50.0000×10^{-4} |
| 10^{-5} | 50.0000×10^{-5} |
| 10^{-6} | 50.0000×10^{-6} |

Preparation of the Sodium Chloride Nebulizers

A portion of each standard solution is transferred to an appropriately labelled nebulizer. The solution transfer is accomplished by removing the top of the nebulizer (Figs. 4-a and 4-b) and extracting the air-inlet post with clean forceps. The interior body of the nebulizer is first rinsed with distilled water, and then with a small volume of the appropriate sodium chloride standard solution. The nebulizer is filled with approximately 30 ml of the corresponding sodium chloride standard solution. The top of the nebulizer and the air-inlet post are thoroughly rinsed with distilled water. After the excess distilled water has drained from the air-inlet post, it is re-inserted into the nebulizer and the top is replaced. The port in the nebulizer's top is covered with a piece of parafilm to prevent evaporation of the solution.

To keep the nebulizers free of contamination, the following guidelines should be implemented [3]:

1. Do not touch the inside of the nebulizers.
2. Do not leave the port in the respective nebulizer's top exposed to air.
3. Use a fresh piece of parafilm each time a nebulizer is recovered.

CALIBRATION PROCEDURE

A PMT voltage response can be measured for each of the 7 sodium chloride standard solutions. A plot of the sodium chloride standard solution concentrations vs. the PMT voltages can be readily accomplished. Since a time-averaged PMT voltage response is measured for the concentration of sodium chloride that has leaked into a respirator during quantitative fit testing, the plot of the sodium chloride standard solution concentrations vs. their

time-averaged PMT voltage responses can be interpolated to determine the concentration of sodium chloride that has leaked into the respirator. The following paragraphs describe the calibration procedure for the RQFT system:

After the sodium chloride RQFT system has been turned on and allowed to stabilize--but before the sodium chloride standard solutions are processed in precalibration--the strip-chart recorder, integrator, and aerosol sampling system are checked for proper operation and calibration. The channel 2 red-pen control (Fig. 15) of the strip-chart recorder amplifier is switched through its range positions of 5 V, 1 V, and 500 mV, and then reset to the 5 V position. If the pen's position changes when the range switch is changed, the hydrogen flame intensity and PMT bias voltage require adjustment. Small incremental changes in the position of the "HYDROGEN PRESSURE CONTROL" knob (Fig. 3-b) and the PMT's bias voltage thumb-wheel switches are made until rotation through the three-range switch positions on the strip-chart recorder result in no change in pen position. The red-pen (channel 2) zero control is adjusted so that it tracks one major division above the baseline on the chart paper. The blue-pen (channel 1) (Fig. 15) is set on its 10-V position so that any drift in the PMT's high-voltage bias can be detected. The blue-pen (channel 1) zero control is adjusted so that it tracks 9 major divisions above the baseline. Figure 16 is a schematic diagram of the voltage divider used to scale the PMT's bias to be compatible with the strip-chart's recorder input. The setting for the red pen was selected to be one major division above the baseline to establish an "artificial" zero baseline, so that any drift below the true one could be detected. A similar argument holds for the blue-pen setting. After clean, dry instrument air is allowed to flow through the "DRYING AIR" and "SAMPLE CARRIER AIR" flowmeters (Fig. 3-b), the artificial baseline setting of the red-pen is checked and adjusted if necessary. The strip-chart recorder "CHART DRIVE" speed control (Fig. 15) is switched to its 2-in./min position.

The integrator is calibrated by releasing the black lock-button on the "ZERO" adjust control knob (Fig. 17). The control is then rotated until the counter increments no more than one count per second. After this adjustment has been accomplished, the control is locked into position [3].

The aerosol sampling system is calibrated by connecting a 5-liters/min flowmeter (Fischer and Porter Company, Part No. 10A1378N33BF, Warminster, PA 18974) to the sample pump. The metal-bellows sample pump draws a constant 7-liters/min air sample from the respirator's visual cavity [3]. However, a 6-liters/min portion of this sample is bled to the ambient atmosphere, and the resulting 1-liter/min sample is diluted with a 14-liters/min flow of clean dry air; this mixture is then analyzed for its sodium chloride content. For calibration of the sampling system to be accomplished, the pump inlet line is connected to the "SAMPLE INLET" (Figs. 6-a and 6-b) hose connection. The outlet line of the sample pump is connected to a "T" fitting. One branch of the "T" fitting is connected to the 5-liters/min flowmeter, while the other branch of the "T" fitting is occluded so that a 1-liter/min flow can be read on the flowmeter (Fig. 9-b). After this calibration step is accomplished, the flowmeter is disconnected from the system, and the "AIR SAMPLE" tube for the hydrogen flame photometer is connected in its place (Figs. 3-b and 5).

The sodium chloride standard solutions are processed prior to an RQFT. When the sodium chloride standards are processed, the operator begins with the

nebulizer containing the 10^{-6} solution and proceeds through the solutions to the 10^{-1} standard. This processing sequence minimizes contamination of a weaker solution by a stronger one. Before a standard is processed, the nebulizer contents are mixed to dissolve any salt particles which may have collected on the walls of the nebulizer. Mixing is readily accomplished by gently swirling the solution in the nebulizer. For a standard to be processed, the air-supply hose is connected to the threaded fitting on the nebulizer, the parafilm cover is removed, and the sampling liquid aerosol line is attached to the port on the top of the nebulizer. The nebulizer is held in place during calibration by lifting the spring-loaded knob on the RQFT instrument's console, positioning the nebulizer into its holder, and releasing the knob. The "CHART DRIVE" switch (Fig. 15) of the strip-chart recorder is toggled, the tracking pens are lowered onto the chart paper by means of the black lever above the chart-paper scale, and the "ATOMIZER AIR" flowmeter valve (Fig. 3-b) is opened. The operator waits for the strip-chart recorder's response to plateau, and records the equilibrated voltage from the integrator's voltmeter display. The "ATOMIZER AIR" flowmeter and "CHART DRIVE" switch of the strip-chart recorder are turned off, the nebulizer is removed from its holder, and its port is covered with a piece of parafilm. This procedure is repeated for each of the calibration solutions. The strip-chart recorder pens should be raised from the paper after the standard solutions have been calibrated. The 10^0 challenge solution is not calibrated until after all RQFT's have been accomplished. This procedure will ensure that the system is not contaminated by this strong concentration of sodium chloride. Actual calibration data are tabulated in Table 2, and a plot of these data is shown in Figure 18 [2,3].

TABLE 2. SODIUM CHLORIDE STANDARD CALIBRATION VOLTAGES

| Sodium chloride calibration standard solution | PMT output voltage (volts) |
|---|----------------------------|
| 10^0 (5% challenge) | 3.355 |
| 10^{-1} | 2.915 |
| 10^{-2} | 2.310 |
| 10^{-3} | 1.500 |
| 10^{-4} | 0.545 |
| 10^{-5} | 0.165 |
| 10^{-6} | 0.105 |

DATA COLLECTION AND REDUCTION

During respirator quantitative fit testing, respirator performance is measured with a strip-chart recorder and an electronic integrator. The RQFT data are reduced, using the USAFSAM DEC VAX-11/780 computer; a set of protection factors result.

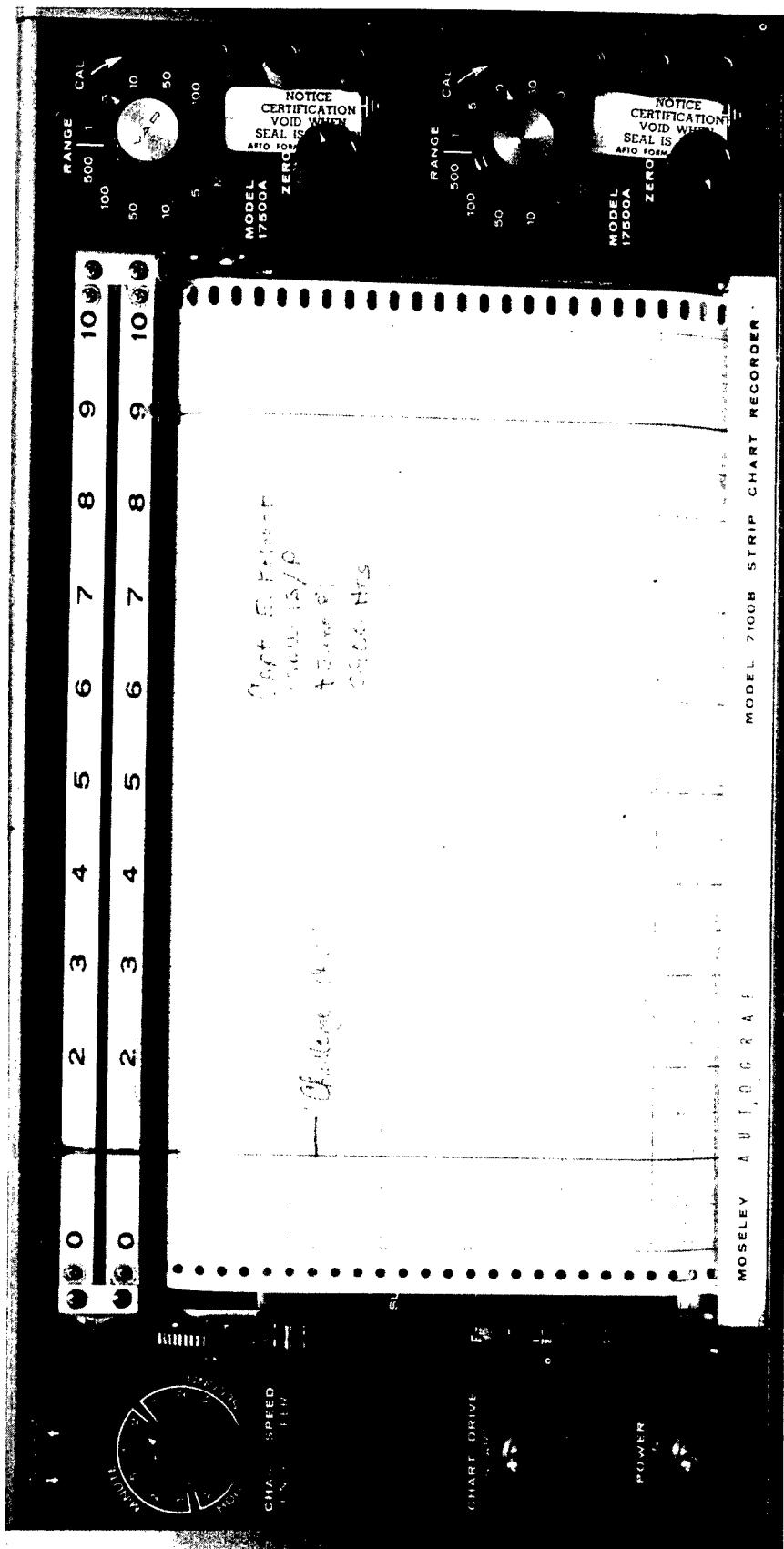


Figure 15. Strip-chart recorder.

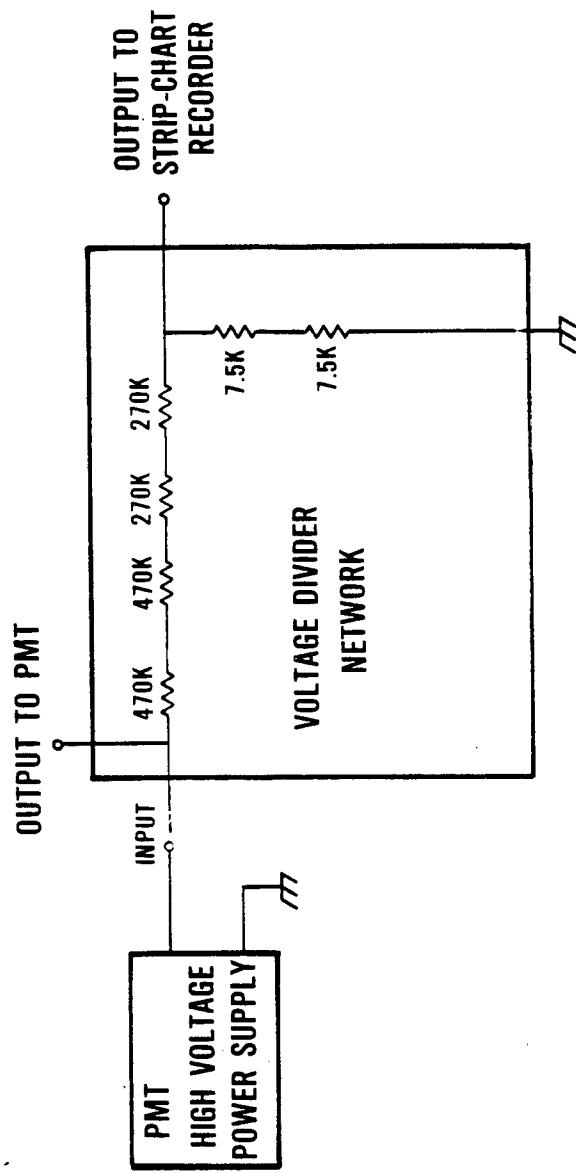


Figure 16. The voltage divider used to scale the PMT's bias to be compatible with the strip-chart's recorder input.

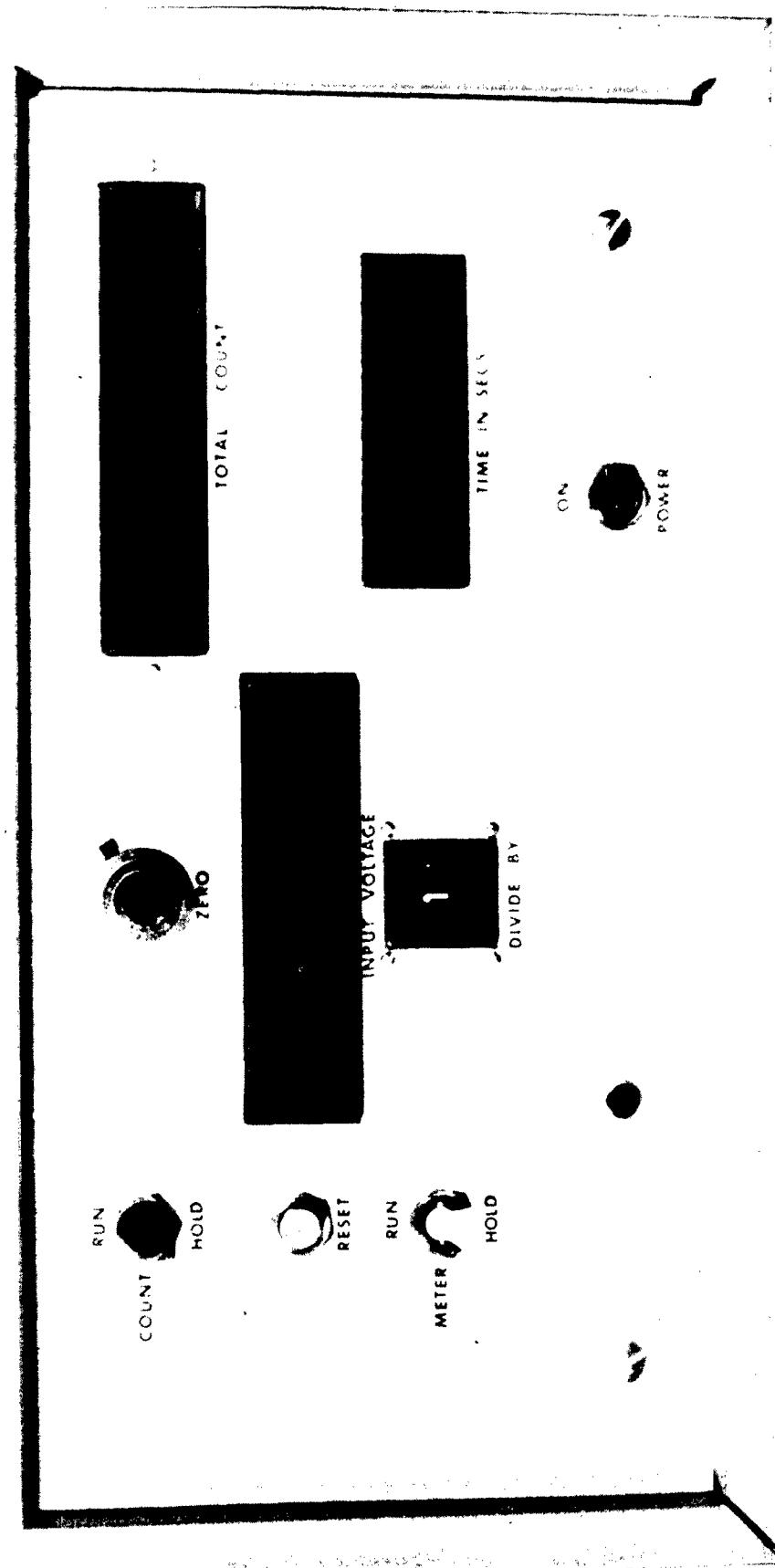


Figure 17. Integrator.

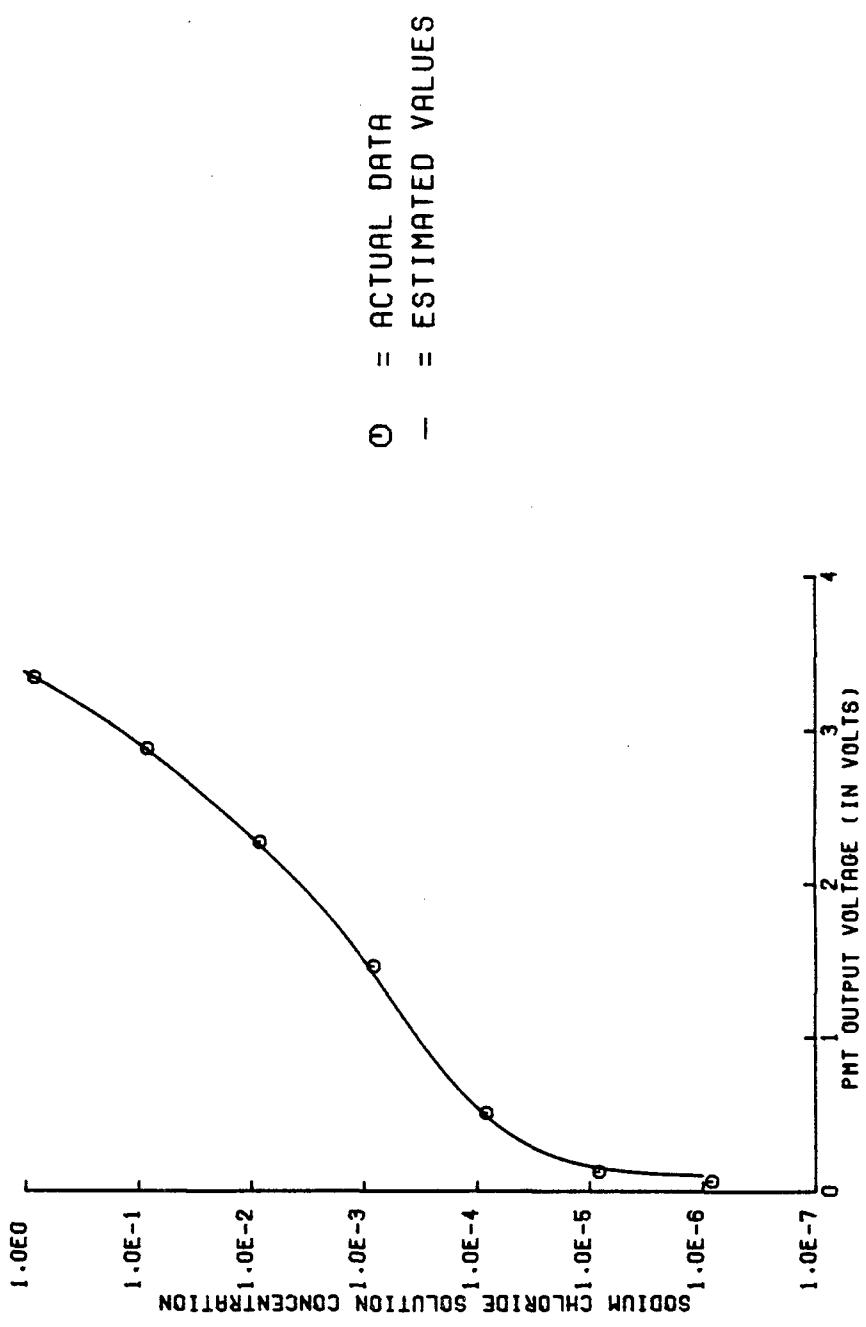


Figure 18. Sodium chloride calibration-challenge concentrations vs. photomultiplier tube (PMT) output voltage.

Protection Factor

A respirator PF is defined as the ratio of the sodium chloride concentration in the ambient challenge atmosphere external to the respiratory protective device to the concentration in the sample air drawn from the interior of the respirator. Mathematically, a PF can be expressed as:

$$PF = \frac{C_a}{C_s} \quad (2)$$

in which PF = protection factor,

C_a = ambient challenge atmosphere concentration, and

C_s = sampled leakage concentration.

A protection factor is a dimensionless quantity; the units of the concentrations cancel in the ratio.

An arithmetic average protection factor (\overline{PF}), calculated for a series of breathing and head-movement exercises, is expressed in mathematical terms as:

$$\overline{PF} = \frac{\sum_{i=1}^n PF_i}{n} \quad (3)$$

in which \overline{PF} = average protection factor for n exercises,

i = the i th exercise, $i = 1, 2, 3, \dots, n$, and

PF = protection factor associated with a specific exercise.

When assigning greater or lesser degrees of relative importance to individual exercise PF's is desirable, a time-weighted average protection factor is calculated. For the time-weighted average protection factor, calculated for a different but predetermined length of time, a mathematical relationship is:

$$\overline{PF}_w = \frac{\sum_{i=1}^n w_i PF_i}{\sum_{i=1}^n w_i} \quad (4)$$

in which \overline{PF}_w = weighted average protection factor for n exercises,

i = the i th exercise, $i = 1, 2, 3, \dots, n$,

w_i = weighting factor for the i th exercise (time), and

PF = protection factor associated with a particular exercise.

Strip-Chart Recorder

The penetration or leakage of the challenge atmosphere into a respirator during quantitative fit testing is continuously displayed on a strip-chart

recorder. Protection factors can be manually calculated using the strip-chart recorder output. Shown in Figure 19 is a strip-chart recording of a typical quantitative fit test for six 10-sec exercises, and the sodium chloride pre-calibration data. The exercises are [2]:

1. normal breathing, looking straight ahead (NB);
2. deep breathing, looking straight ahead (DB);
3. deep breathing and turning head side to side (TH);
4. deep breathing and moving head up and down (UD);
5. talking (T); and
6. facial grimacing (FG).

At the far right side of Figure 19, the subject and the type of respirator are identified. Next, the sodium chloride standard solution calibration data are displayed, and then the strip-chart recorder response for the 6 exercises. Each of the exercises was performed for a fixed period of time (10 sec). During each exercise, as the test subject inhaled, a slight negative pressure was created in the facepiece, thus increasing the penetration of the challenge atmosphere into the respirator. This phenomenon is recorded as a peak by the strip-chart recorder. A slight positive pressure, created during exhalation, acts to reduce the penetration of the challenge atmosphere into the respirator. On the strip-chart recorder, this phenomenon is recorded as a valley. Respirator leakage performance is based on the average of the penetration peaks and valleys recorded during each exercise. The average leakage is determined by drawing a line through the "visual" midpoint of the peaks and valleys, and extending the line to intersect the calibration curve (Fig. 19). A plot of the sodium chloride calibration concentrations vs. their strip-chart recorder displacements produces a logarithmic relationship (Fig. 20) [2]. Therefore, logarithmic interpolation can be used to determine the average penetration value between adjacent calibration decades. An exercise PF is calculated using Eq. 2. Since the concentration of sodium chloride in the challenge atmosphere is 10^0 or 1, and the concentration of sodium chloride in the respirator's sampled air is the average leakage concentration, the protection factor is equal to the reciprocal of the exercise average leakage concentration. The average leakage concentrations and corresponding protection factors for the data in Figure 19 are shown in Table 3 [2].

TABLE 3. PENETRATION VALUES AND PROTECTION FACTORS

| Exercises | Average penetration | Protection factor |
|-----------|----------------------|-------------------|
| NB | 5.5×10^{-5} | 1.8×10^4 |
| DB | 7.7×10^{-5} | 1.3×10^4 |
| TH | 7.2×10^{-5} | 1.4×10^4 |
| UD | 5.5×10^{-5} | 1.8×10^4 |
| T | 5.9×10^{-5} | 1.7×10^4 |
| FG | 8.3×10^{-5} | 1.2×10^4 |

Overall average PF = 1.5×10^4 .

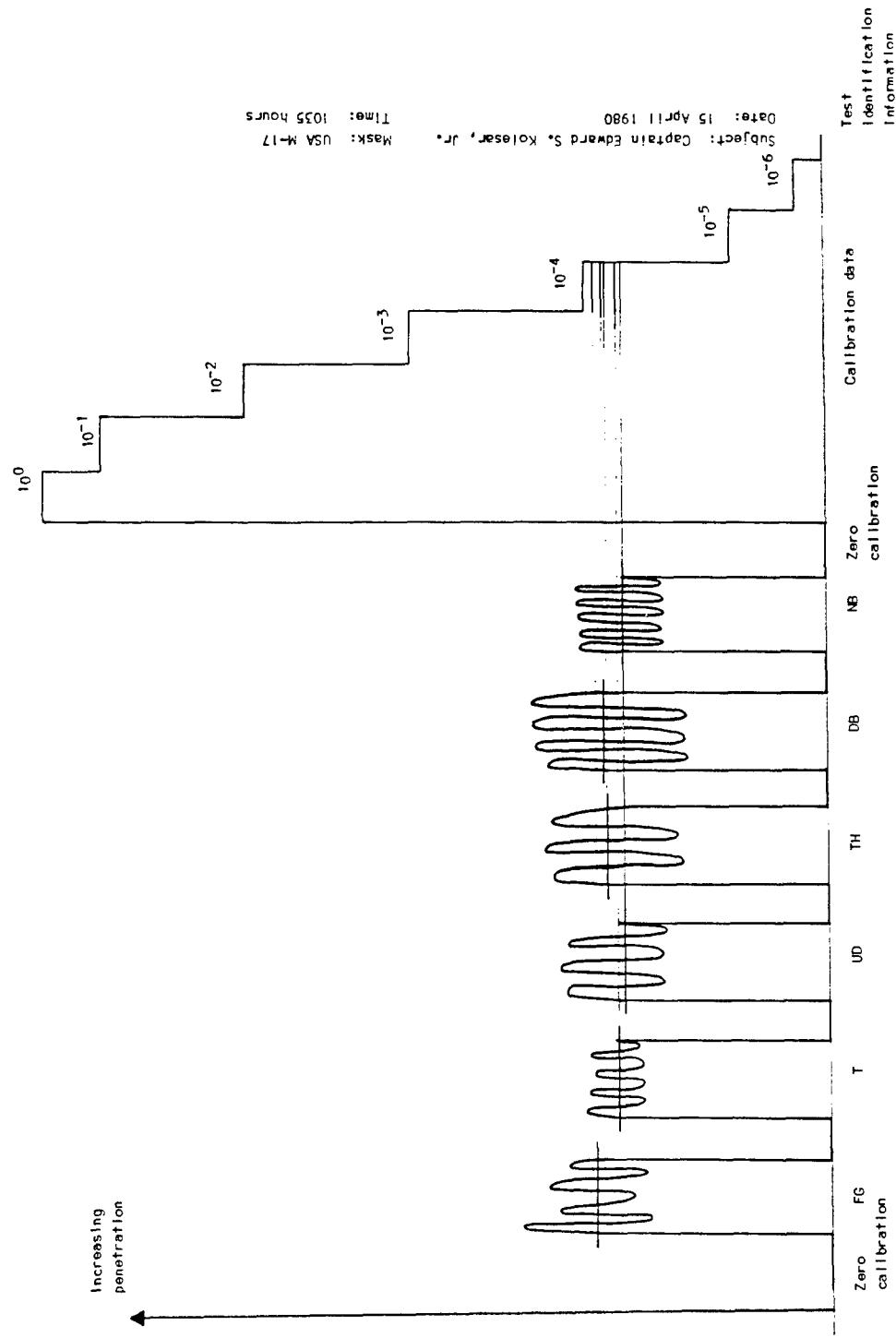


Figure 19. Sodium chloride respirator quantitative fit test strip-chart recording. [FG = facial grimacing; T = talking; UD = deep breathing and moving head up and down; TH = deep breathing and turning head side to side; DB = deep breathing, looking straight ahead; and NB = normal breathing, looking straight ahead]

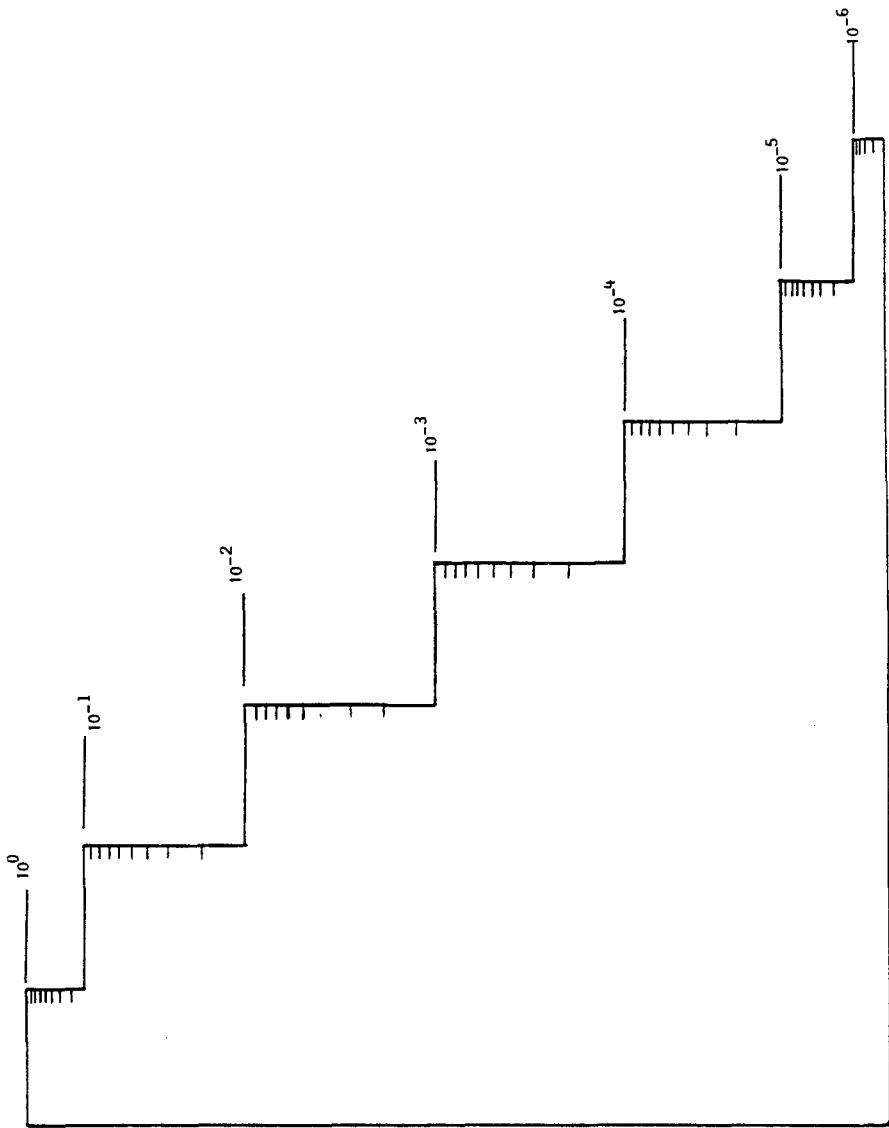


Figure 20. Logarithmically scaled sodium chloride calibration data used to interpolate mask leakage concentration.

The strip-chart recorder method of calculating PF's is very cumbersome. Therefore an alternative method of calculating PF's, utilizing the USAFSAM DEC VAX-11/780 computer and the electronic integrator, has been developed.

Voltage-to-Frequency Converter Electronic Integrator

The voltage-to-frequency (V/F) converter electronic integrator transforms the analog voltage signal from the photomultiplier tube into a pulse train whose repetition rate (frequency) is a direct function of PMT's voltage response. A counter stage is added to the V/F converter's output to accumulate the pulses. The accumulated pulse count is equal to the "area under the strip-chart recorder's voltage curve" or time-averaged integral. Figure 21 illustrates the operating principle of a V/F converter integrator. Voltage-to-frequency digital integrators have important advantages [2]:

1. The counter can be easily switched to a "HOLD" position, and the integrated count can be held indefinitely.
2. The digital counter can be preset to any value and integrated up or down from that point.
3. Standard electro-optical readouts--such as Nixie tubes, light-emitting diodes (LED's), etc.--can be adapted to display the integrated count.

The major components of the V/F converter electronic integrator are listed in Table 4. Figure 22 (views a, b, and c) are schematic diagrams of the integrator circuit used in the USAFSAM sodium chloride RQFT instrument. The digital display schematic diagram is shown in Figure 23; and the voltmeter, in Figure 24.

The USAFSAM sodium chloride RQFT instrument integrator utilizes the Analog Devices AD450J V/F converter integrated circuit module. Shown in Figure 25 is a block diagram of the converter's internal functions; and in Table 5, the electronic specifications for the device are summarized. The AD450J is an inexpensive high-performance V/F converter that provides exceptional linearity and temperature stability over a wide dynamic input signal range [2].

The USAFSAM sodium chloride RQFT V/F integrator is very simple to operate. The analog voltage signal to be integrated (strip-chart recorder input signal) is connected to the appropriate terminal (Fig. 22-a). When the integrator is energized with the ON/OFF switch, the neon lamp on the front panel indicates a power flow. The operating voltages for the integrator's digital integrated circuits are provided by two direct-current power supplies, ± 15 V and +5 V [2].

The sodium chloride RQFT instrument's PMT output signal is biased with a low-level noise component (typically, 2 - 3 mV). An operational amplifier (Precision Monolithics, Model No. OP-7, Santa Clara, CA 95050) buffer circuit is used to compensate for this noise signal.

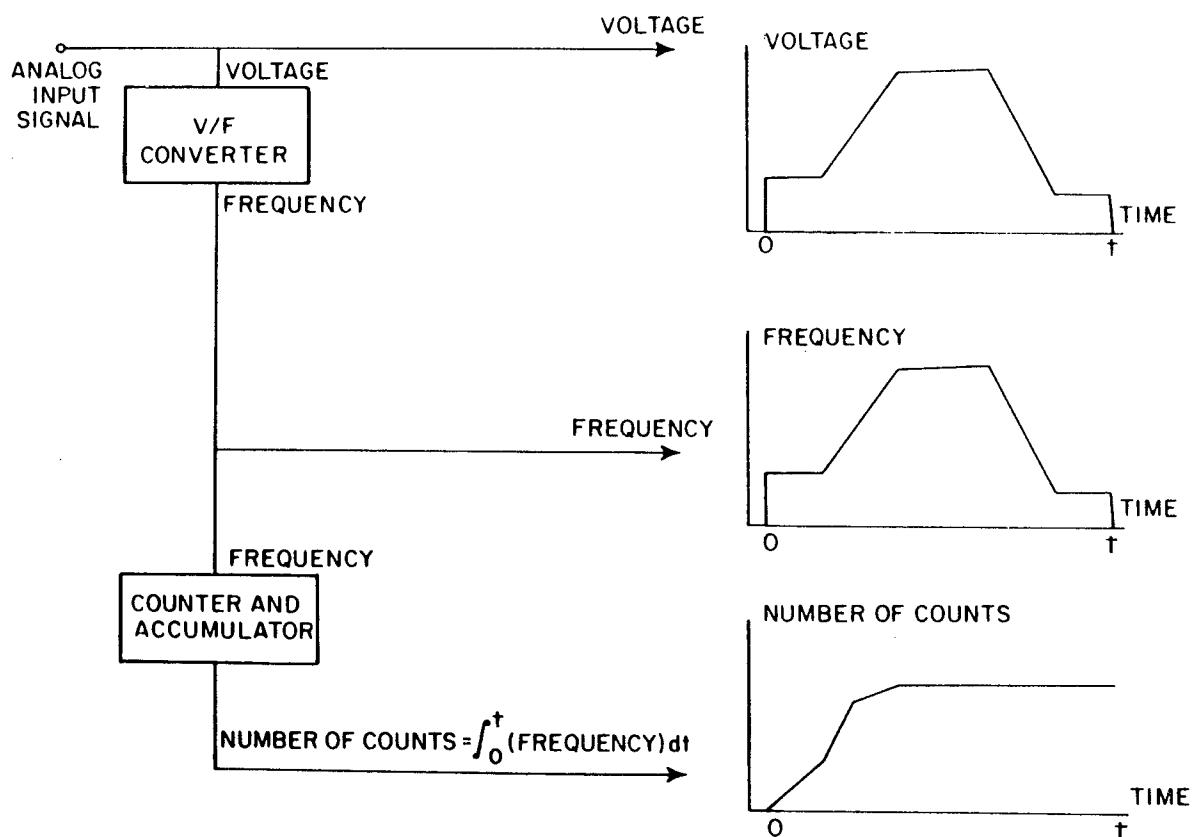


Figure 21. Operating principle of a voltage-to-frequency integrator.

TABLE 4. MAJOR COMPONENTS OF THE VOLTAGE-TO-FREQUENCY CONVERTER
ELECTRONIC INTEGRATOR

| Schematic diagram references (Figs. 22, 23) | Description |
|---|---------------------------------|
| R1 | 27K ohms, 1/4 watt, 5% |
| R2 | 1K ohms, 1/4 watt, 5% |
| R3 | 20K ohms, 1/4 watt, 5% |
| R4 | 500-ohm variable potentiometer |
| R5 | 50K-ohm variable potentiometer |
| R6 | 100K ohms, 1/4 watt, 5% |
| R7 | 100K ohms, 1/4 watt, 5% |
| R8 | 50K ohms, 1/4 watt, 5% |
| R9 | 100K ohms, 1/4 watt, 5% |
| R10 | 50K ohms, 1/4 watt, 5% |
| R11 | 100K ohms, 1/4 watt, 5% |
| R12 | 100K ohms, 1/4 watt, 5% |
| R13 | 15K ohms, 1/4 watt, 5% |
| R14 | 10K ohms, 1/4 watt, 5% |
| R15 | 1K ohms, 1/4 watt, 5% |
| R16 | 100K-ohm variable potentiometer |
| R17 | 10K ohms, 1/4 watt, 5% |
| C1 | 0.1-microfarad capacitor |
| T1 | 2N956 NPN transistor |

(Cont'd. on facing page)

TABLE 4 (Cont'd.)

| Schematic diagram references (Figs. 22, 23) | Description |
|---|--|
| IC1 | Precision Monolithics Incorporated, operational amplifier, OP-7 |
| IC2 | Analog Devices Incorporated, high performance V/F converter, AD450J |
| IC3 | Motorola Semiconductor Products Incorporated, decade counter/divider, MC14017B |
| IC4 | Motorola Semiconductor Products Incorporated, noninverting hex buffers, MC14050B, V_{CC} - Pin 1, V_{SS} - Pin 8, Ground Pins 11 and 14, $V_{CC} = +5$ V |
| IC5 | Motorola Semiconductor Products Incorporated, quad 2-input OR gate, MC14071B, V_{CC} - Pin 14, V_{SS} - Pin 7, Ground Pins 5, 6, 7, 8, 9, 12, and 13, $V_{CC} = +5$ volts. |
| IC6 | Texas Instruments Incorporated, hex inverter, SN7404, V_{CC} - Pin 14, V_{SS} - Pin 7, $V_{CC} = +5$ V |
| IC7 | Motorola Semiconductor Products Incorporated, industrial time base generator, MC14566B |
| Digital Display Module - Integrator Count | Dialight LED display module 749-1706 |
| Digital Display Module - Integration Time | Dialight LED display module 749-1704 |

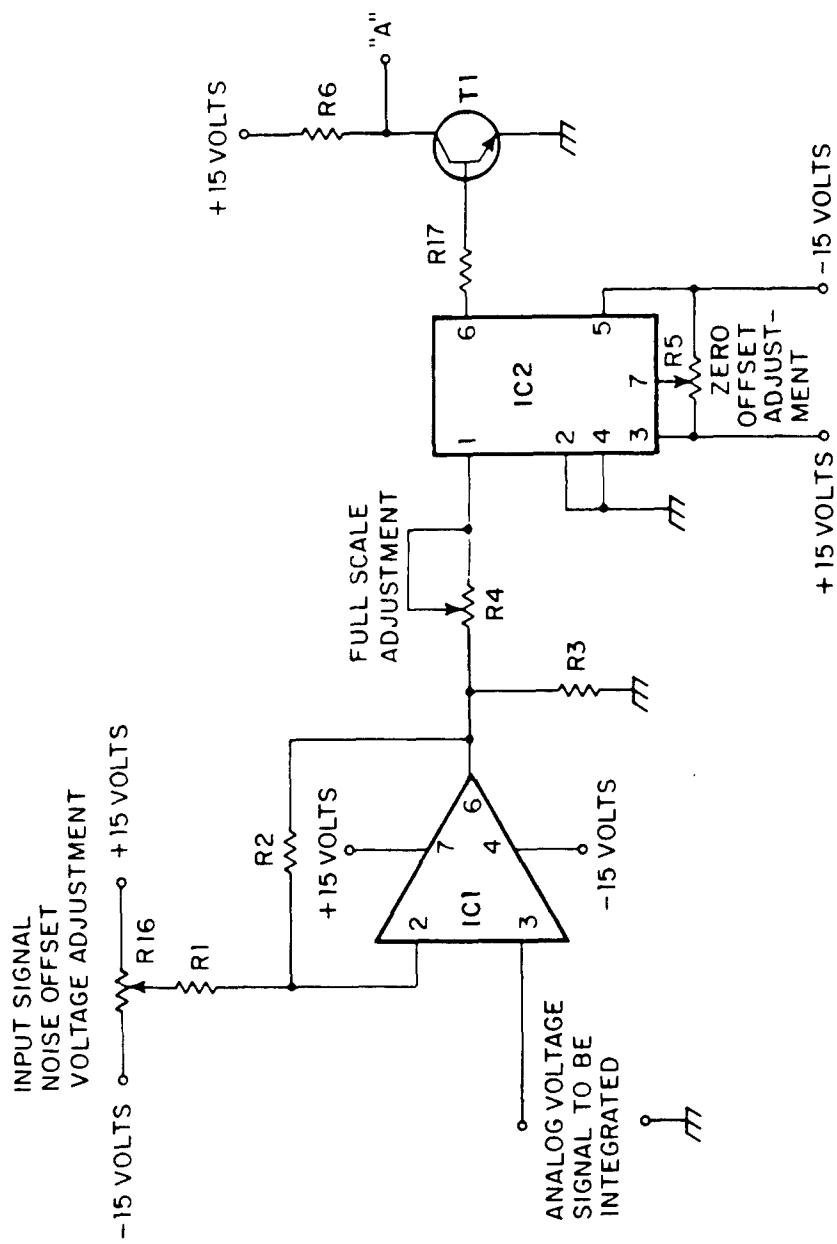


Figure 22-a. Sodium chloride respirator quantitative fit test instrument integrator (schematic diagram, continued in views b and c).

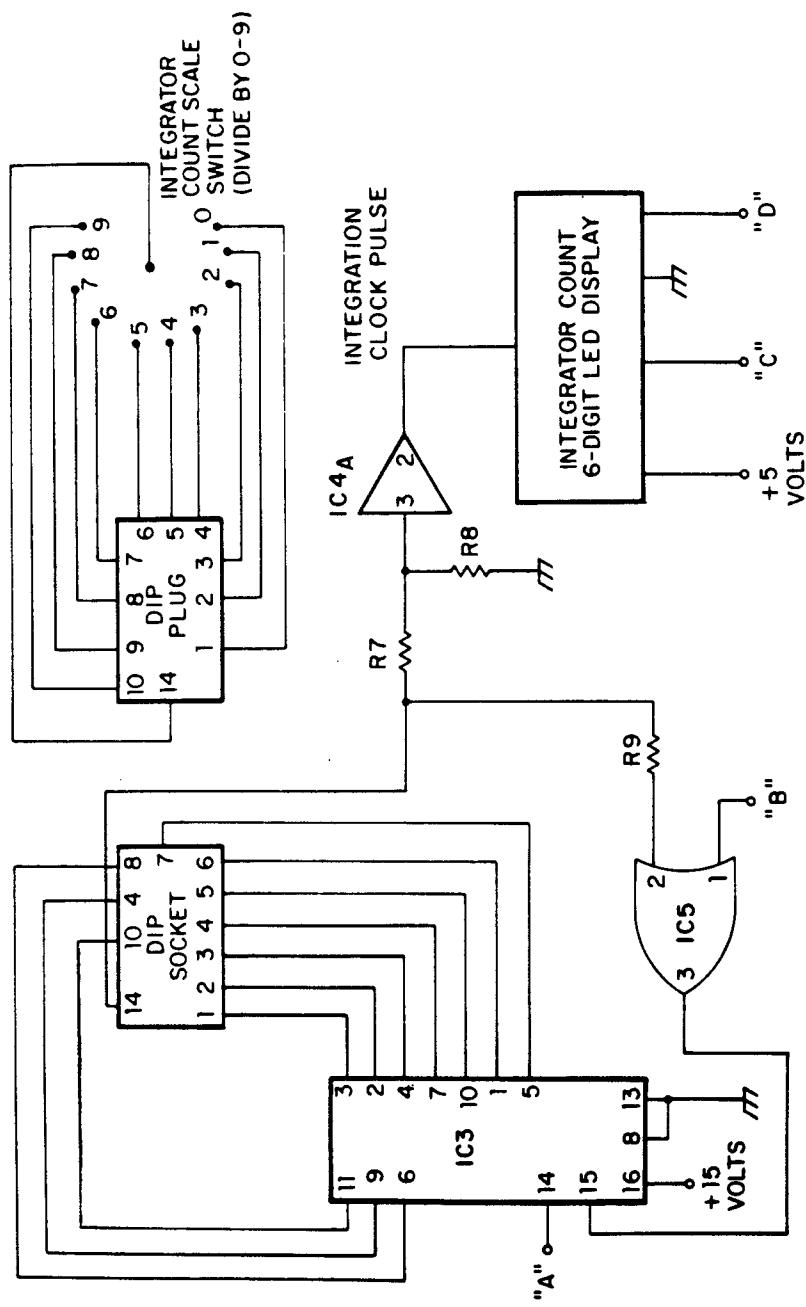


Figure 22-b. Sodium chloride respirator quantitative fit test instrument integrator (schematic diagram, concluded in view c).

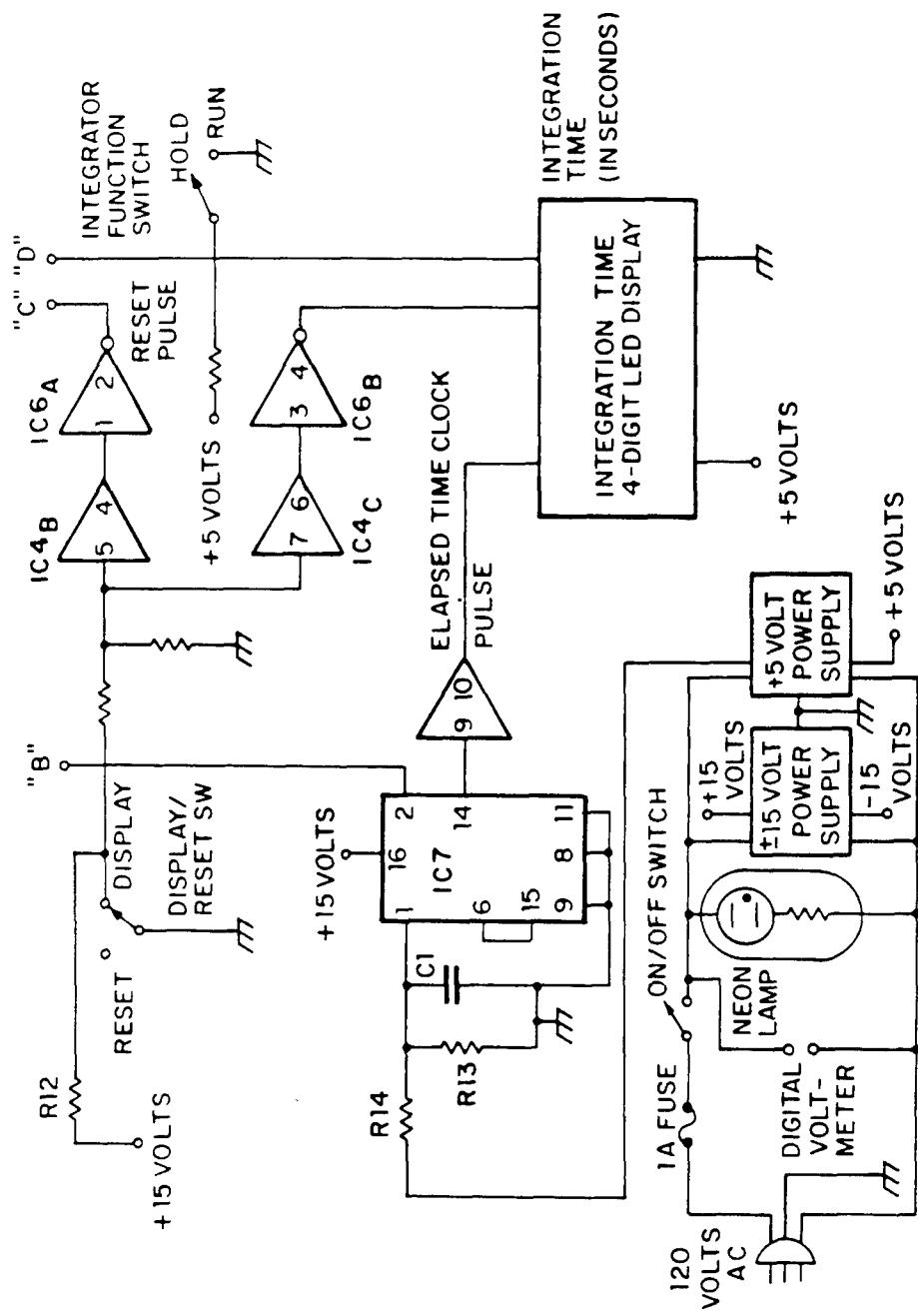


Figure 22-c. Sodium chloride respirator quantitative fit test instrument integrator (concluding schematic diagram of views a - c).

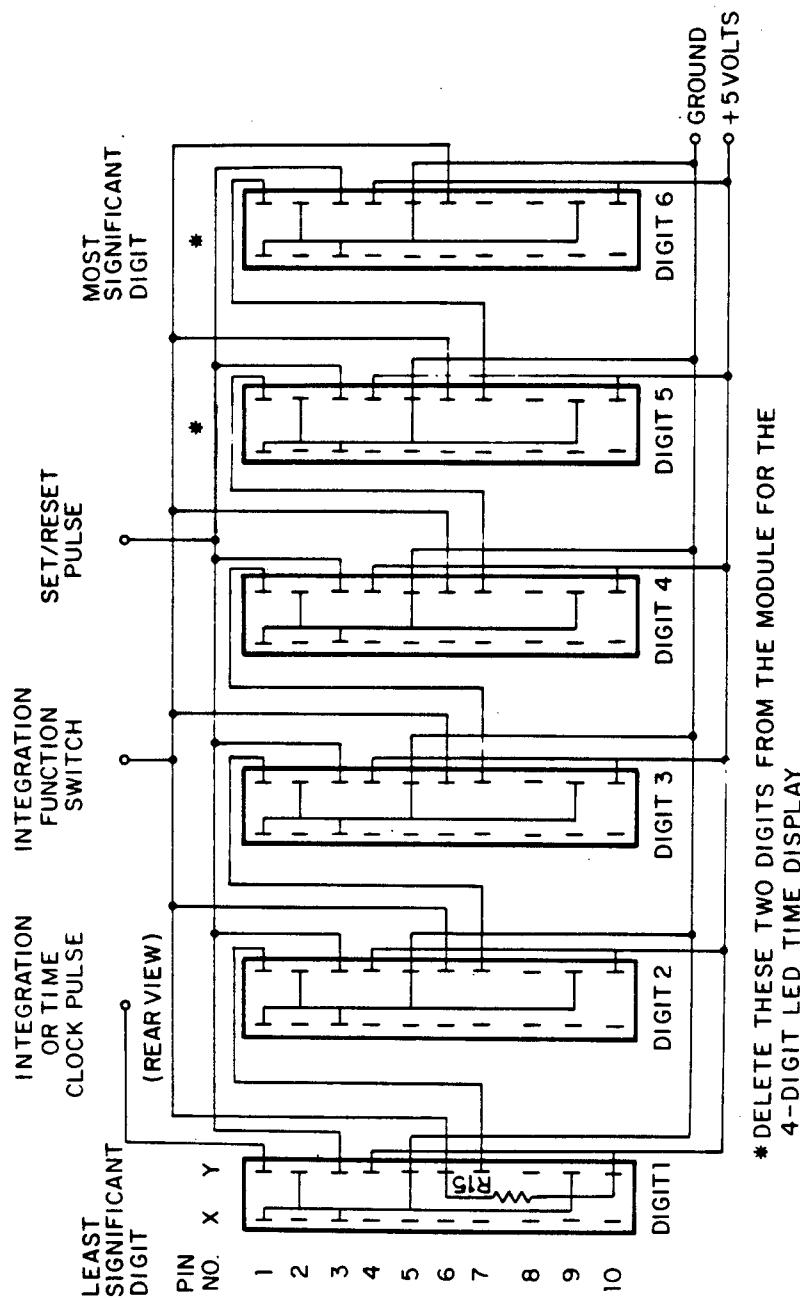


Figure 23. Sodium chloride respirator quantitative fit test instrument integrator digital display.

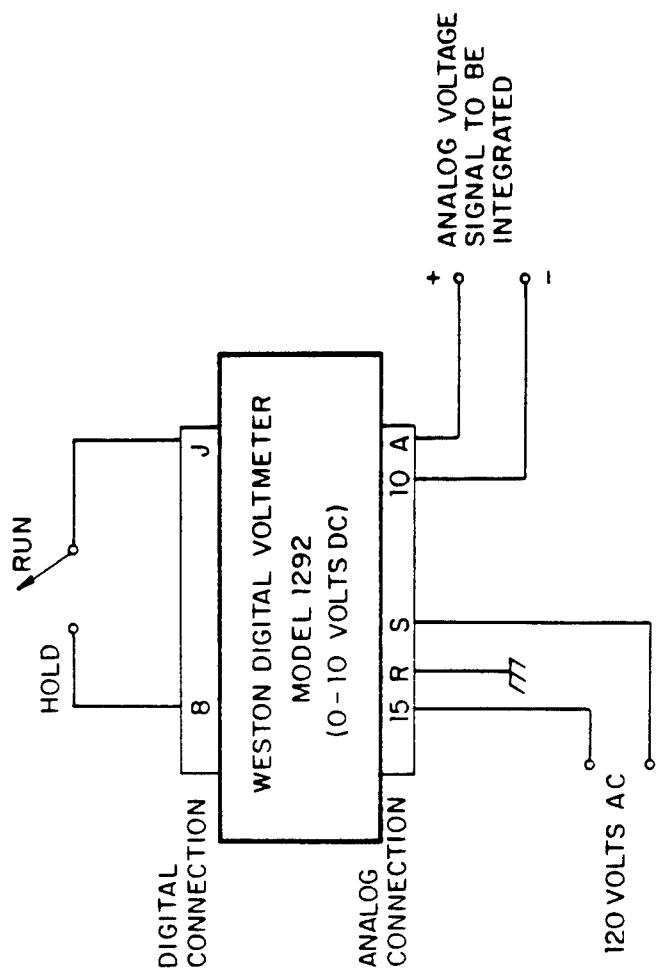


Figure 24. Sodium chloride respirator quantitative fit test instrument integrator voltmeter schematic.

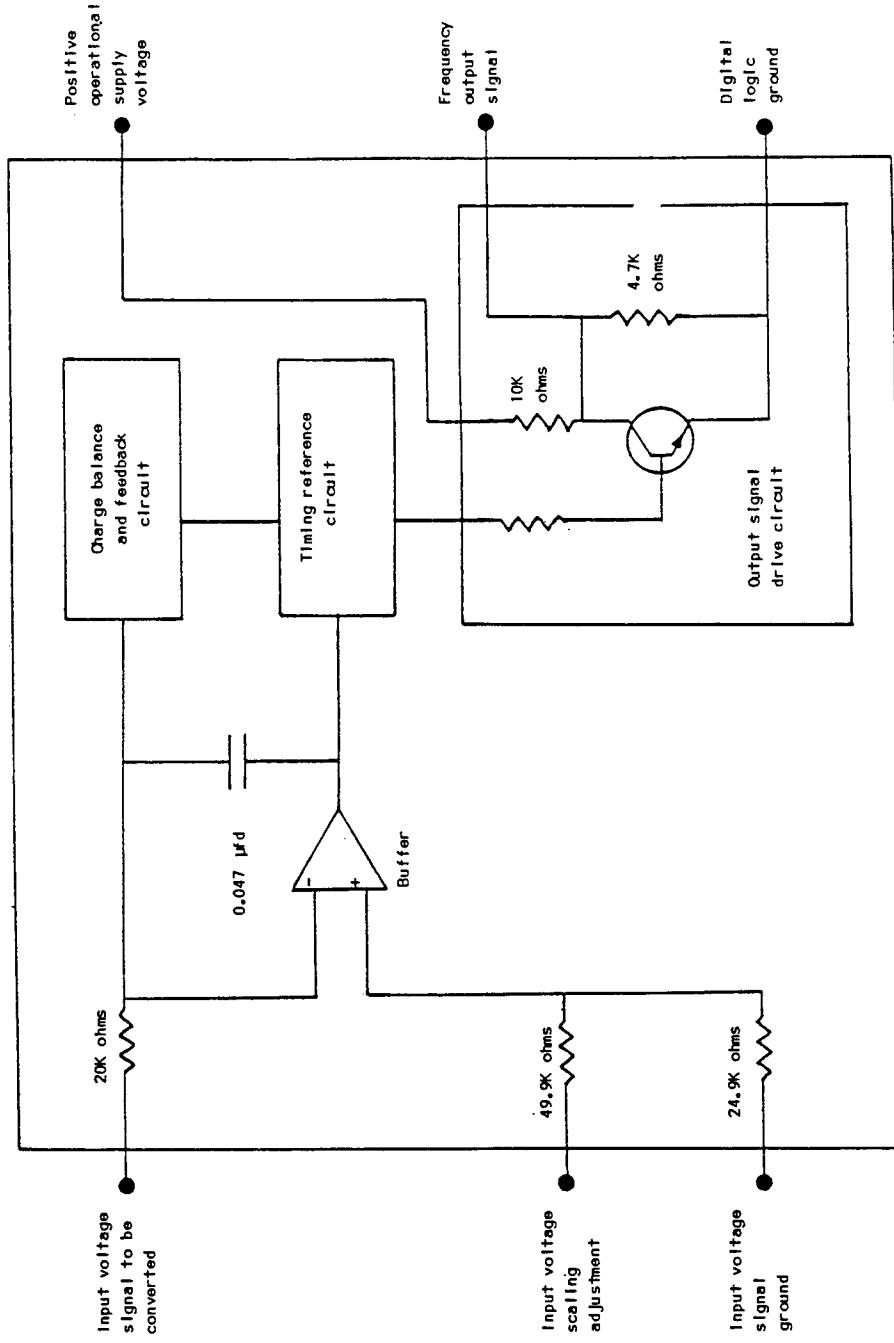


Figure 25. Internal functions of the Analog Devices AD450J voltage-to-frequency converter.

TABLE 5. ELECTRONIC SPECIFICATIONS OF THE ANALOG DEVICES AD450J VOLTAGE-TO-FREQUENCY CONVERTER

| Characteristic | Value |
|--|--|
| TRANSFER FUNCTION | |
| Voltage Input | $f_{out} = (10^3 \frac{\text{Hz}}{\text{V}}) e_{in}$ |
| ANALOG INPUT | |
| Voltage Signal Range (e_{in}) | 0 to +10V min |
| Overrange | 50% min |
| Impedance (e_{in}) | 20k Ω |
| Max Safe Input Voltage (e_{in}) | +25V (- V_s) |
| ACCURACY | |
| Warmup Time | 1 min |
| Nonlinearity | |
| $e_{in} = +1mV$ to $+15V$ | $\pm 0.01\%$ max |
| Full-Scale Error | 1.5% max |
| Gain | |
| vs. Temperature (0 to 70°C) | $\pm 50\text{ppm}/^\circ\text{C}$ max |
| vs. Supply Voltage | $\pm 200\text{ppm}/\%$ max |
| vs. Time | $\pm 100\text{ppm}/\text{day}$ |
| Input Offset Voltage | $\pm 5\text{mV}$ max |
| vs. Temperature (0 to 70°C) | $+50\mu\text{V}/^\circ\text{C}$ |
| vs. Supply Voltage | $\pm 10 \text{ ppm}/\%$ max |
| vs. Time | $\pm 10\mu\text{V}/\text{day}$ |

(Cont'd. on facing page)

TABLE 5 (Cont'd.)

| Characteristic | Value |
|-----------------------------------|------------------------------------|
| RESPONSE | |
| Settling Time for +10V Step Input | 120 μ s |
| Overload Recovery Time | 15ms |
| OUTPUT | |
| Waveform | Train of TTL/DTL compatible pulses |
| Pulse Width | 50 μ s |
| Rise/Fall Time | 200ns |
| Pulse Polarity | positive |
| Logic "1" (High) Level | +2.4V min |
| Logic "0" (Low) Level | +0.4V max |
| Capacitive Loading | 1000pF max |
| Fan Out Loading | 10 TTL loads min |
| Impedance | 3.3k Ω |
| POWER SUPPLY | |
| Voltage, Rated Performance | \pm 15V dc |
| Voltage, Operating | \pm (12 to 18)V dc |
| Current, Quiescent | (+15, -9)mA |
| TEMPERATURE RANGE | |
| Rated Performance | 0 to +70°C |
| Operating | -25°C to +80°C |
| Storage | -55°C to +85°C |
| CASE SIZE | (1.5 x 1.5 x 0.4) in. |

DTL = diode-transistor logic; and TTL = transistor-transistor logic.

The Analog Devices AD450J V/F converter transforms the PMT's analog voltage signal into a pulse train which is accumulated and displayed on the 6-digit LED integrator count display. When signals are to be integrated for a long time, an integrator count dividing constant may be selected to keep the integrator count display from overloading. The operator selects a dividing constant (1 to 9) with the thumb-wheel ("DIVIDE BY") switch on the integrator's front panel (Fig. 17). The magnitude of the integrator count digital display must be multiplied by the switch position number to obtain the actual integrator count.

The integrator is designed with an internal time base generator (Motorola Semiconductor Products, Model No. MC14566 integrated circuit, Phoenix, AZ 85036). A clocked output pulse is produced each second, and the accumulated time (in seconds) is recorded on the 4-digit LED display.

The operator has complete control over the length of time a signal is integrated, during an RQFT, via the integrator's "RUN/HOLD" switch and "RESET" button (Fig. 17). The "RUN/HOLD" switch is toggled to the "RUN" position to start the integrator "TIME" and "TOTAL COUNT," and to the "HOLD" position to stop the counters when an exercise has been completed. Depressing the "RESET" button clears the integrator "TIME" and "TOTAL COUNT" displays to zero for the next exercise. Manual control of the integrator permits the operator to start and stop the counters as desired, and allows the integrator count and time for a particular exercise to be recorded [2].

Data Collection

The RQFT data is generated and displayed on the V/F integrator's LED displays. Prior to an RQFT, the sodium chloride calibration solutions are used to precalibrate the instrument. A steady-state output voltage is displayed on the integrator's digital voltmeter for each of the 6 calibration standards and the challenge solution. These voltages nominally range 3.400 to 0.030 V. Each voltage is recorded adjacent to the corresponding sodium chloride calibration standard concentration on the data sheet shown in Figures 26 or 27. Subject name, respirator type, date, and time are also recorded on the data sheet. The test subject then performs a set of 6 or 16 exercises, each for a predetermined time period. For each exercise, the integration count and elapsed time are displayed on the LED displays. These data are recorded on the data sheet adjacent the corresponding exercise. The 6-exercise protocol is itemized in Figure 26; and the 16-exercise protocol, in Figure 27 [2]. The data from an exercise sheet are keyed into a computer terminal for reduction.

Computer Calculation

The calculation of PF's is accomplished by the computer, with the method of least-squares curve fitting; the computer program uses the sodium chloride standard calibration data and calculates an interpolating least-squares curve-fit polynomial equation. The integrator count data for a test exercise is scaled and substituted into the polynomial equation to calculate a corresponding mask leakage concentration (C_S). A PF is calculated by taking the reciprocal of this mask leakage concentration [2].

OPERATION OF THE SODIUM CHLORIDE RESPIRATOR QUANTITATIVE FIT TEST INSTRUMENT

The RQFT system must reach an operating equilibrium and be calibrated before a respirator evaluation is conducted. The following sequence of procedures and adjustments is required to bring the system to operational status:

"Start-up" Procedure

1. Toggle the AC power supply switch to the "ON" position (Fig. 28).
2. Toggle the PMT power supply (Hewlett-Packard, Model No. 6516A DC power supply, Palo Alto, CA 94304) to the "ON" position (Fig. 28).
3. Set the voltage of the PMT power supply at 1428 V, with the thumb-wheel switches; from right to left, they increment by 1, 10, 100, and 1000 V (Fig. 28).
4. Turn on the air compressor and its cleaning and drying unit.
5. Turn on the instrument air (valve located behind the console).
6. Adjust the "LINE AIR PRESSURE CONTROL" to 70 psi (482.7 kPa) (Fig. 29).
7. Check the "DRYING AIR" flowmeter; it should indicate 85% (use the bottom of the bell as an indicator). The "DRYING AIR" flow can be adjusted by rotating the knob directly below the flowmeter (Fig. 30).
8. Check the "SAMPLE CARRIER AIR" flowmeter setting; it should indicate 16 (use the bottom of the float as an indicator). The "SAMPLE CARRIER AIR" can be adjusted by rotating the knob directly below the flowmeter (Fig. 30).

Hydrogen Flame Ignition

The following 8 steps are necessary for proper hydrogen flame ignition:

1. Insure that all the hydrogen valves are closed except for the "HYDROGEN PRESSURE CONTROL" valve (Fig. 3-b).
2. Remove the top two sections of the photometer's "VERTICAL FLAME" column (Figs. 3-a and 3-b).
3. Open the hydrogen high-pressure valve, and adjust the low-pressure regulator to 20 psi (137.9 kPa) (Fig. 31).

4. Open the low-pressure regulator valve (Matheson Gas Corporation, Model No. 70 regulator and Model No. 63-4111 gauge, East Rutherford, NJ 07073) very slowly (opening the valve too quickly will result in damage to the water manometer); it should be set at 5 psi (34.5 kPa) (Fig. 5).
5. Wait several seconds for the hydrogen gas to flow through the plumbing and reach the gas jet located inside the "VERTICAL FLAME" column (Fig. 2-b).
6. Ignite the hydrogen at the jet by using a long wooden match or electrical spark lighter. The hydrogen flame is pale-blue and almost colorless. Do not look directly into the flame column; eye damage could result.
7. Adjust the height of the flame to 1 in. (2.54 cm) by using the micrometer "HYDROGEN PRESSURE CONTROL" (Figs. 3-a and 3-b); this setting will correspond to a water manometer reading of 4.5 cm. The micrometer valve is extremely sensitive; over-tightening could damage the valve and the water manometer.
8. Replace the top two sections of the "VERTICAL FLAME" column. These sections will soon become too hot to touch (Fig. 3-b).

Integrator and Strip-Chart Recorder Preparation

The 3 following steps are essential in the preparation of the integrator and strip-chart recorder:

1. Toggle the integrator "POWER" supply switch to the "ON" position (Fig. 17).
2. Toggle the voltmeter switch to the "RUN" position (Fig. 17).
3. Toggle the strip-chart recorder "POWER" supply switch to the "ON" position (Fig. 15).

The RQFT instrument must be allowed to stabilize for approximately 30 min before the hardware and sodium chloride standard solutions are calibrated. After this equilibration period has elapsed, the directions for calibration in the "Calibration Procedure" section can be implemented.

Respirator Evaluation

The RQFT system is now ready for respirator evaluation. The "ATOMIZER AIR" flow (Fig. 30) should be off, and the "LINE AIR PRESSURE" control (Fig. 29) should be set at 70 psi (482.7 kPa). The subject dons a respirator and related protective equipment. If the respirator requires an external source of breathing gas, the source should be connected to the respirator at this time. The open end of the respirator leakage sampling hose (internal to the plastic hood enclosure) is connected to the respirator's aluminum sampling port (Fig. 8-b). The subject sits under the transparent plastic hood which is

then lowered to cover the subject's head and upper torso. The cloth collar is drawn snugly around the subject's waist (Fig. 7-b). The operator now implements the following sequence of steps to complete an RQFT evaluation:

1. Disconnect the bypass tubing (on the side of the console) from the "SAMPLE INLET" port (Fig. 6), and connect the open end of the respirator leakage sampling hose (external to the plastic hood enclosure) to the "SAMPLE INLET" port.
2. Disconnect the bypass tubing from the "SALT SOURCE OUTLET" port (Fig. 6), and connect the challenge atmosphere delivery hose to the "SALT SOURCE OUTLET" port.
3. Insert the 10^0 nebulizer into its holder (Fig. 4-a).
4. Open the "ATOMIZER AIR" valve (Fig. 30) for maximum flow.
5. Toggle the strip-chart recorder "CHART DRIVE" to its "START" position (Fig. 15).
6. Lower the strip-chart recorder pens onto the chart paper.

The test subject will sit quietly for 3 min while a salt cloud forms and equilibrates in the hood; the integrator's elapsed time display can be utilized to keep track of the minutes. Under the direction of the RQFT operator, the subject performs a set of head-movement and breathing exercises; each exercise is performed for a predetermined period. The time and integrator count for each exercise is recorded (Fig. 32). After the respirator evaluation has been completed, the "ATOMIZER AIR" valve (Fig. 30) is closed and the bypass tubing is reconnected (Fig. 6); it should be connected first to the "SALT SOURCE OUTLET" port, and then to the "SAMPLE INLET" port. The 10^0 challenge solution is processed according to directions in the "Calibration Procedure" section.

"Shutdown" Procedure

1. Toggle the strip-chart recorder (Fig. 15) and integrator (Fig. 17) power-supply switches to their "OFF" positions.
2. Turn off the hydrogen supply high-pressure valve, wait for the residual gas to burn, and verify that the low-pressure regulator gauge returns to zero (Fig. 31).
3. Close the hydrogen supply low-pressure valve (located in the back of the instrument's console) (Fig. 5) when the low-pressure gauge is at zero.
4. Turn off the instrument air supply.
5. Toggle the AC power supply switch to "OFF" position (Fig. 28).

RESPIRATOR QUANTITATIVE FIT TESTING
-USAFSAM SALT FOG INSTRUMENTATION-

Concentration

10 to the Zero
10 to the Minus One
10 to the Minus Two
10 to the Minus Three
10 to the Minus Four
10 to the Minus Five
10 to the Minus Six

Voltage (In Volts)

SUBJECT NAME:

TYPE OF MASK:

DATE TESTED:

TIME TESTED:

Exercise

Count

Time Period
(In Seconds)

Normal Breathing Straight Ahead

Normal Breathing Straight Ahead

Deep Breathing

Side-to-Side Head Movements (Deep Breathing)

Up-and-Down Head Movements (Deep Breathing)

Facial Grimacing

| | | | | |
|--|--|--|--|--|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

A 4x3 grid of 12 empty squares, used for drawing or writing.

Figure 26. Data collection sheet for 6-exercise protocol.

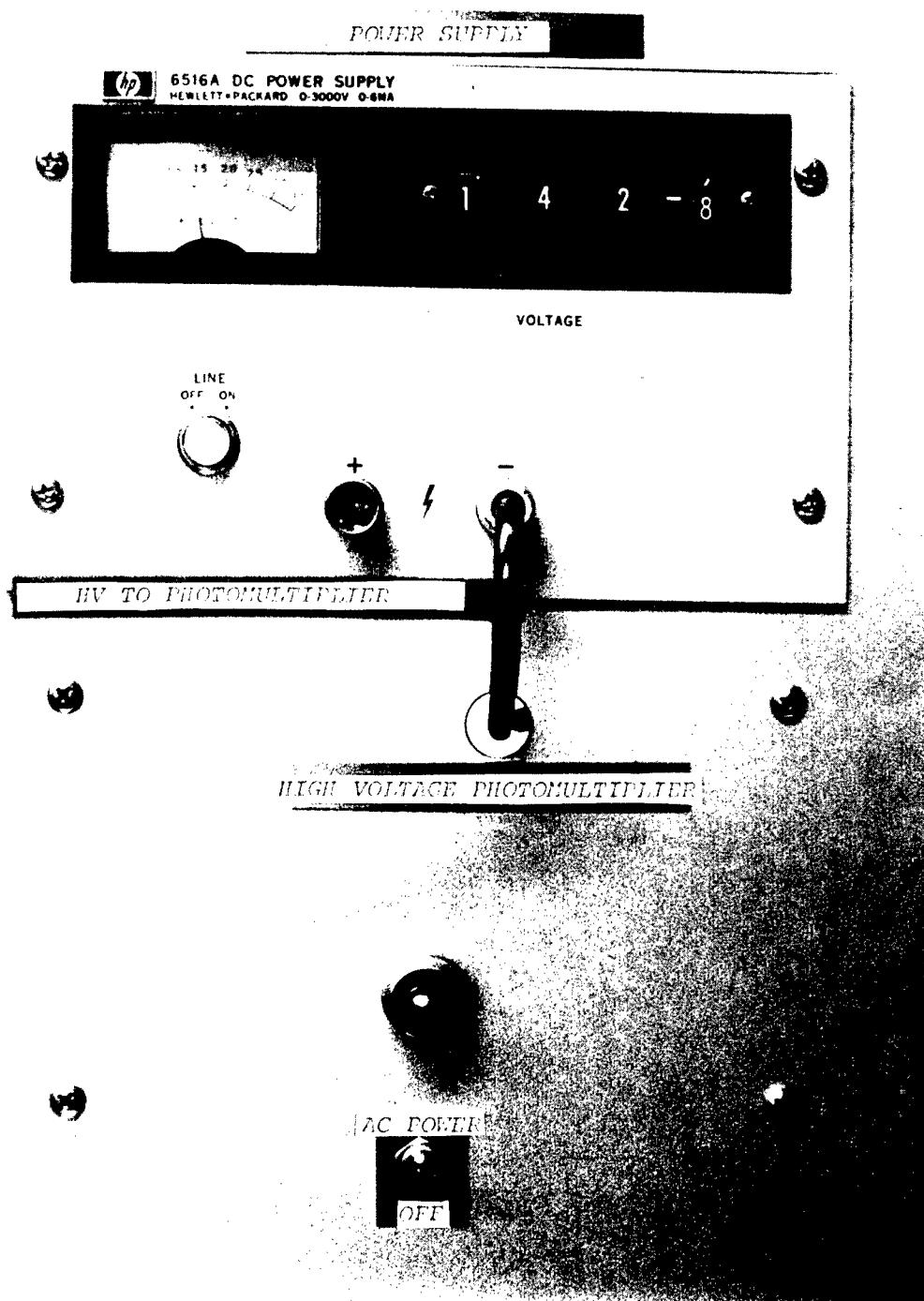


Figure 28. Respirator quantitative fit test instrument power supply.

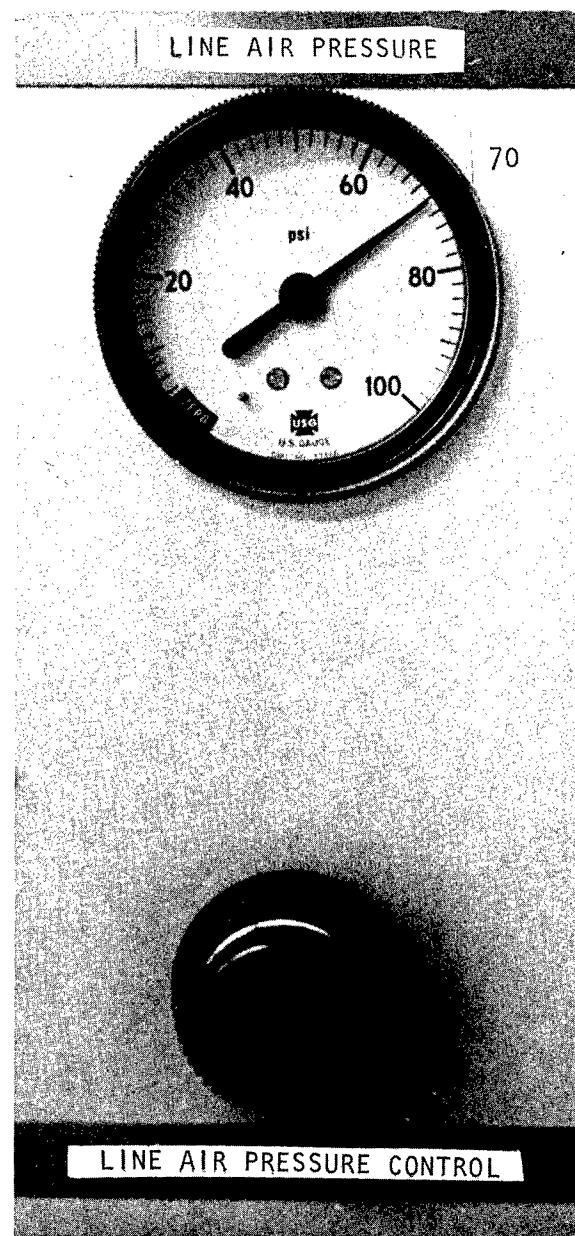


Figure 29. Line air pressure gauge and control.

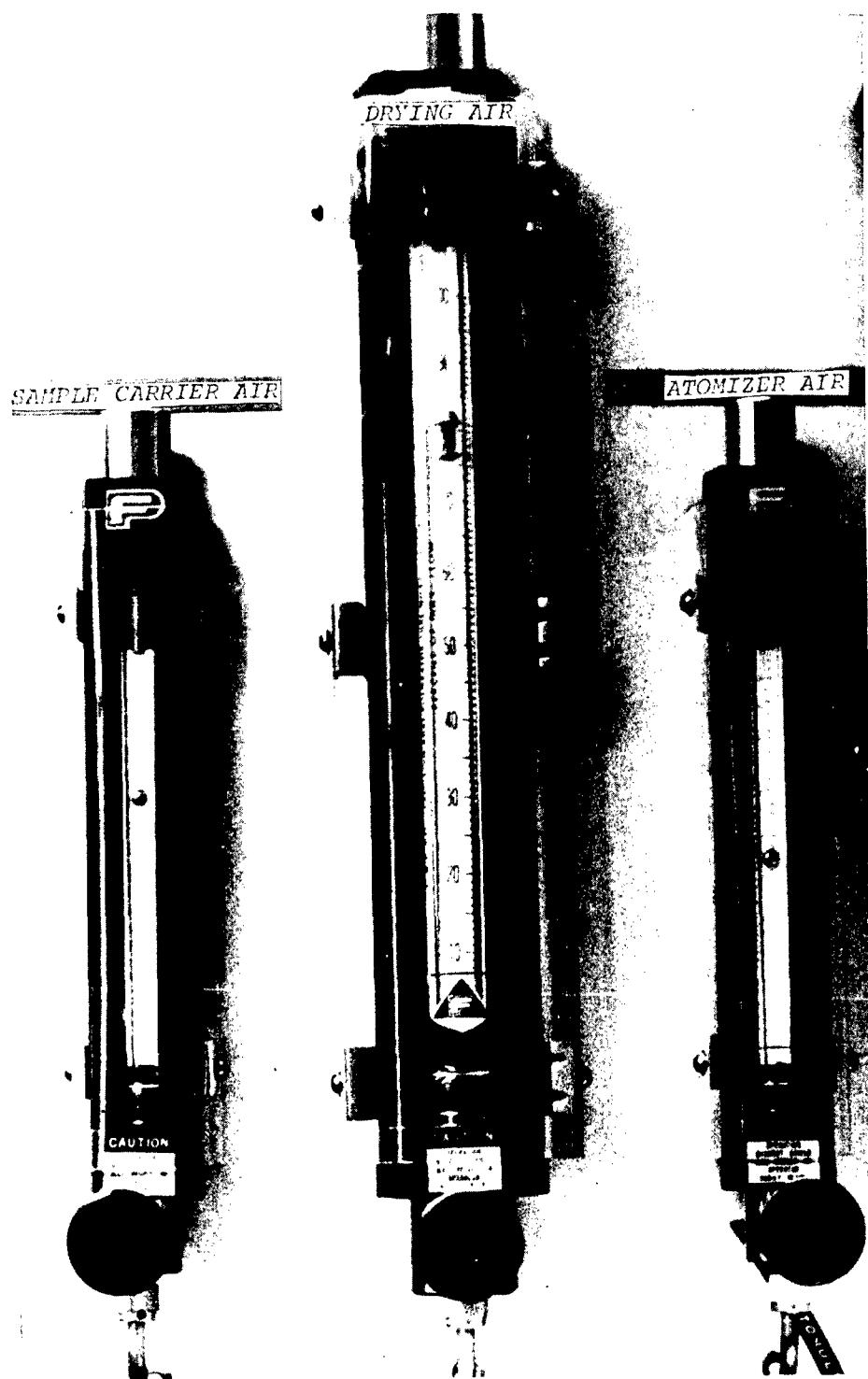


Figure 30. Respirator quantitative fit test instrument flowmeters.

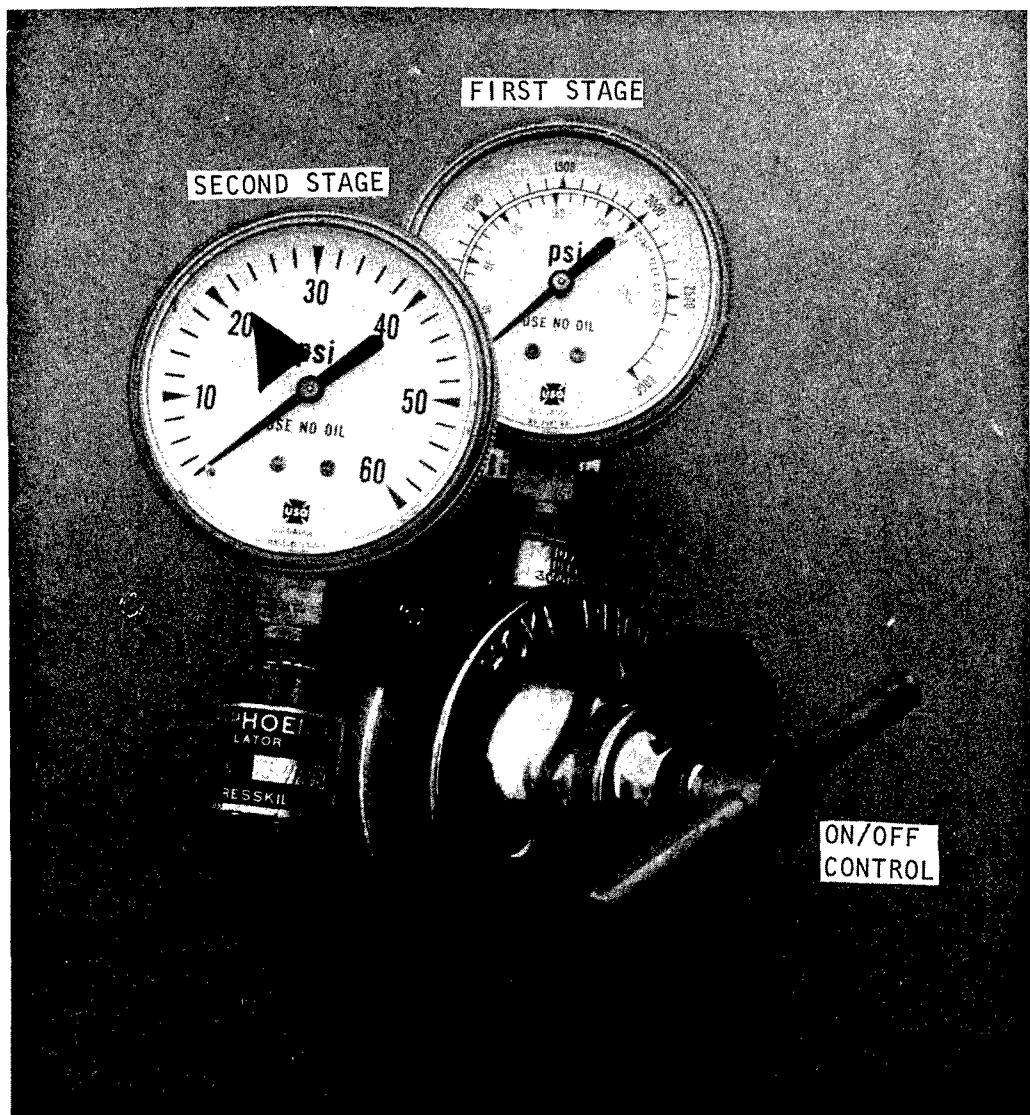


Figure 31. Two-stage hydrogen pressure regulator.

6. Toggle, to their "OFF" positions, the air compressor and the cleaning and drying power switches. (These switches are located behind the plastic hood).
7. Insert the distilled water nebulizer into its holder.
8. Lower the recorder pens onto the chart paper to keep them from drying out.

The data recorded during respirator evaluation can be analyzed and reduced using the USAFSAM DEC VAX-11/780 computer. Using a terminal, the operator enters the data into the computer; the output is a set of PF's that characterize the respirator fit and performance.

MAINTENANCE

General Instrument Cleaning

After extensive respirator testing (approximately 6 test subjects) the aerosol sampling and detection subsystems may become contaminated with sodium chloride particles; a clue to contamination is an unstable strip-chart recorder zero baseline. Three options (a-c) exist for cleaning the RQFT instrument: (a) To bring the red tracking pen back to the zero baseline, the distilled water nebulizer is connected, and the "ATOMIZER AIR" valve is set for maximum flow. A good practice is to process distilled water through the system between each respirator evaluation. (b) For extensive contamination, clean dry compressed instrument air can be flushed through the system overnight. (c) If the zero baseline continues to be unstable, the respirator leakage air sampling assembly must be dismantled and washed with distilled water. To accomplish this maintenance procedure:

1. Remove the sample pump from the RQFT instrument (Fig. 5).
2. Connect the pump inlet line to the distilled water source, and place the outlet line in a collection pan.
3. Turn on the pump and distilled water flow.
4. Allow distilled water to flow through the pump for several seconds.
5. Turn off the pump and distilled water flow.
6. Reconnect the pump to the RQFT instrument, turn on the instrument air, and allow the pump to dry (Fig. 9-a).
7. Disconnect the drying tube from the instrument (Figs. 3-b and 5).
8. Disconnect the Tygon tubing that attaches to the nebulizer (Figs. 4-a and 5).
9. Rinse each of these components thoroughly with distilled water, and reconnect to the RQFT instrument.



Figure 32. Respirator quantitative fit test instrumentation, as the time and the integrator count for each exercise are being recorded.

10. Remove the distilled water nebulizer, and rinse it thoroughly with distilled water.
11. Refill the distilled water nebulizer, and connect it to the RQFT instrument.
12. Allow the RQFT instrument to dry completely before a respirator evaluation is attempted.

Hydrogen Flame Photometer Jet Cleaning

The hydrogen jet and inner surfaces of the "VERTICAL FLAME" column may become contaminated with sodium chloride particles. If an unstable zero baseline persists after the aerosol sampling and detection assemblies for the RQFT instrument have been thoroughly cleaned, then the "HYDROGEN" jet and "VERTICAL FLAME" column (Fig. 3-b) should be swabbed with isopropyl alcohol, rinsed with distilled water, and allowed to air-dry before being reassembled.

Photomultiplier Tube Replacement

Replacing the PMT may become necessary. If the PMT is not sensitive to the 10^{-6} standard solution during precalibration, and if the RQFT system has indeed been thoroughly cleaned and properly calibrated, then the PMT must be replaced.

CONCLUSION

The USAFSAM RQFT instrument satisfies an international need for a simple and rugged, yet sensitive and accurate tool for fitting respirators. In addition to its use in the U.S. Air Force, the RQFT is being used at the Chemical Systems Laboratory (Edgewood, MD), the Defense and Civil Institute of Environmental Medicine (Downsview, Ontario, Canada), and the Royal Air Force Institute of Aviation Medicine (Farnborough, Hants, United Kingdom). With respect to this instrument, the most significant achievement thus far implemented by USAFSAM has been the automated analytical algorithm to collect and reduce the protection factor data. As a result, the man-hours per respirator fit trial have been reduced by more than 50%, and human mathematical errors have been eliminated.

CITED REFERENCES

1. Kolesar, E. S. Respirator qualitative/quantitative fit test method analysis. SAM Aeromed Rev 2-80, Aug 1980.
2. Kolesar, E. S. Automated calculation of protection factors for the sodium chloride respirator quantitative fit test instrument. SAM-TR-80-50, Dec 1980.
3. Sodium chloride test system instruction manual. Internal report (not published), USAF School of Aerospace Medicine, Crew Protection Branch, Brooks Air Force Base, Tex. (most current revision, 25 Jan 1979).

4. McConville, J. T., and E. Churchill. Human variability and respirator sizing. Yellow Springs, Ohio: Webb Associates, Inc., Mar 1976.
5. Stein, R. L. Selected head and facial dimensions of mine rescue team personnel. Am Ind Hyg Assoc J 39:576 (1978).
6. White, J. M. Facepiece leakage and fitting of respirators. Canadian Standards Association, Toronto, Ontario, Canada (1978).
7. NATO Standardization Agreement (Standard First Draft STANAG 3864 AMD). The measurement of protection provided to the respiratory tract and eyes against NBC agents in particulate aerosol and vapor form. MAS (Air) (79) (68), 29 Mar 1979.

SUPPLEMENTAL REFERENCES

British Standard (BS) 4400. Method for sodium chloride particulate test for respirator filters. British Standards Institution, British Standards House, London, England (1969).

Douglas, D. D., P. L. Lowry, C. P. Richards, L. A. Geoffrion, S. K. Yasuda, L. D. Wheat, and J. M. Bustos. Respiratory studies for the National Institute for Occupational Safety and Health. Progress report LA-7317-PR. Los Alamos Scientific Laboratory, Los Alamos, N.M. (Jan 1 - Dec 31, 1977).

Ferber, B. I., F. J. Brendenborg, and A. Rhude. Penetration of sodium chloride aerosol through respirator filters. Am Ind Hyg Assoc J 12:791 (1972).

Haunam, R. F., D. J. Morgan, D. T. O'Conner, and R. J. Sherwood. The evaluation of protection provided by respirators. Am Occup Hyg J 7:353 (1964).

Held, B. J., W. H. Revior, J. A. Pritchard, A. A. Hack, L. A. Geoffrion, E. C. Hyatt, T. O. Davis, P. L. Lowry, C. P. Richards, and L. D. Wheat. Respiratory studies for the National Institute for Occupational Safety and Health. Progress report LA-5805-PR. Los Alamos Scientific Laboratory, Los Alamos, N.M. (July 1, 1973 - June 30, 1974).

Hyatt, E. C. Respirator protection factors. Informal report LA-6084-MS. Los Alamos Scientific Laboratory, Los Alamos, N.M. (Jan 1976).

Hyatt, E. C., J. A. Pritchard, B. J. Held, D. A. Bevis, T. O. Davis, L. A. Geoffrion, A. L. Hack, P. L. Lowry, T. O. Moore, C. P. Richards, and L. D. Wheat. Respiratory studies for the National Institute for Occupational Safety and Health. Progress report LA-5620-PR. Los Alamos Scientific Laboratory, Los Alamos, N.M. (July 1, 1972 - June 3, 1973).

White, J. M., and R. J. Beal. The measurement of leakage of respirators. Am Ind Hyg Assoc J 27:239 (1966).

ABBREVIATIONS, ACRONYMS, AND SYMBOLS

| | |
|---------|--|
| AC | alternating current |
| ASCC | Air Standardization Coordinating Committee |
| cm | centimeter |
| CW | chemical warfare |
| DB | deep breathing, looking straight ahead |
| DC | direct current |
| FG | facial grimacing |
| g | gram |
| ITT | International Telephone and Telegraph |
| kPa | kilo-Pascals |
| LED | light-emitting diode |
| μ A | microampere |
| mg | milligram |
| min | minute; minimum |
| ml | milliliter |
| μ m | micrometer |
| MMAD | mass medium aerodynamic diameter |
| mV | millivolt |
| nA | nanoampere |

(Cont'd. on facing page)

ABBREVIATIONS, ACRONYMS, AND SYMBOLS (Cont'd.)

| | |
|-----------|--|
| NB | normal breathing, looking straight ahead |
| nm | nanometer |
| PF | protection factor |
| <u>PF</u> | average protection factor |
| PMT | photomultiplier tube |
| psi | pounds-per-square inch |
| RQFT | respirator quantitative fit test |
| SAM | School of Aerospace Medicine |
| STP | standard temperature and pressure |
| T | talking |
| TH | deep breathing and turning head side to side |
| UD | deep breathing and moving head up and down |
| US, U.S. | United States |
| USAF | United States Air Force |
| USAFSAM | USAF School of Aerospace Medicine |
| V | volts, voltage |
| V/F | voltage-to-frequency |